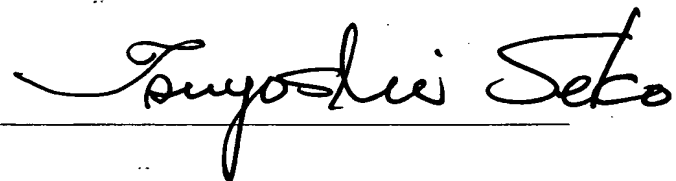# VERIFICATION

I, Tsuyoshi Seko, a national of Japan, NITTO IPO Ltd.,
8th Floor No.17 Arai Building, 1-3-3 Shinkawa, Chuo-ku,
Tokyo 104-0033 Japan, verify that to the best of my knowledge and
belief the following are true translation made by me of the annexed
documents   which are Japanese Application No. 2000-101239 filed
on March 31, 2000.

Dated this 23th day of April, 2004

Tsuyoshi Seko

Tsuyoshi Seko, Translator

[Inventor]
    [Address] 280, Higashi-koigakubo 1-chome, Kokubunji-shi,
         Tokyo
         Hitachi, Ltd. Central Research Laboratory
    [Name]   Kimio TATSUNO

[Inventor]
    [Address] 280, Higashi-koigakubo 1-chome, Kokubunji-shi,
         Tokyo
         Hitachi, Ltd. Central Research Laboratory
    [Name]   Tatemi IDO

[Inventor]
    [Address] 216, Totsuka-cho, Totsuka-ku, Yokohama-shi,
         Kanagawa-ken
         Hitachi, Ltd. Communications Division
    [Name]   Yasunori IWAFUJI

[Inventor]
    [Address] 216, Totsuka-cho, Totsuka-ku, Yokohama-shi,
         Kanagawa-ken
         Hitachi, Ltd. Communications Division
    [Name]   Hideyuki KUWANO

[Inventor]
    [Address] 216, Totsuka-cho, Totsuka-ku, Yokohama-shi,
         Kanagawa-ken
         Hitachi, Ltd. Communications Division

[Name]   Naohiko BABA

[Applicant for Patent]
     [Identification No.]   000005108
     [Name]   Hitachi, Ltd.

[Agent]
     [Identification No.]   100068504
     [Patent Attorney]
     [Name]   Katsuo OGAWA
     [Telephone No.]   03-3661-0071

[Appointed Agent]
     [Identification No.]   100086656
     [Patent Attorney]
     [Name]   Kyosuke TANAKA
     [Telephone No.]   03-3661-0071

[Designation of Fee]
     [Ledger No. for Deposit]   081423
     [Amount of Payment]   21000

[List of Submitted Document]
     [Object Name]   Specification   1
     [Object Name]   Drawings   1
     [Object Name]   Abstract   1

[Necessity of Proof] Required

[Name of Document] SPECIFICATION

[Title of the Invention]

OPTICAL FIBER COMMUNICATION EQUIPMENT AND ITS APPLIED

OPTICAL SYSTEMS

[What is claimed is]

[Claim 1]

Optical-fiber communication equipment comprising at least, a laser light source, a means for changing light of the laser light source to a parallel plane wave to form a parallel light path, a wavelength selection means having two or more transmission bands, and a first and a second light detector, wherein:

said wavelength selection means is located in the parallel light path;

the parallel plane wave is divided into at least two pieces of light: light that is transmitted through said wavelength selection means; and light passing through a medium having optical characteristics different from those of the light that is transmitted through said wavelength selection means;

the first light detector detects one of the divided pieces of light and the second light detector detects the other divided light;

signals based on photocurrents from the first and the second light detector are compared to each other to

obtain a signal for setting an emitting wavelength of the laser light source to a desired value; and

said signal is used for controlling a wavelength of the laser light source.

[Claim 2]

Optical-fiber communication equipment comprising at least, a laser light source, a means for changing light of the laser light source to a parallel plane wave to form a parallel light path, an optical system for dividing the parallel plane wave, a wavelength selection means having two or more transmission bands, and a first and a second light detector, wherein:

said wavelength selection means is located in the parallel light path;

said optical system for dividing the parallel plane wave divides the parallel plane wave into at least two pieces of light: light that is transmitted through said wavelength selection means; and the other light;

the first light detector detects one of the divided pieces of light and the second light detector detects the other divided light;

signals based on photocurrents from the first and the second light detector are compared to each other to obtain a signal for setting an emitting wavelength of the laser light source to a desired value; and

said signal is used for controlling a wavelength of the laser light source.

[Claim 3]

Optical-fiber communication equipment comprising at least, a laser light source, a means for changing light of the laser light source to a parallel plane wave to form a parallel light path, an optical system for dividing the parallel plane wave, a wavelength selection means, and a first and a second light detector, wherein:

said wavelength selection means is located in the parallel light path;

said wavelength selection means has a plurality of light transmission portions having desired wavelengths existing at given wavelength intervals;

any one of the plurality of light transmission portions corresponds to an emitting wavelength desired by the laser light source;

said optical system for dividing the parallel plane wave divides the parallel plane wave into at least two pieces of light: light that is transmitted through said wavelength selection means; and light passing through a medium having optical characteristics different from those of the light that is transmitted through said wavelength selection means;

the first light detector detects one of the divided

pieces of light and the second light detector detects the other divided light;

signals from the first and the second light detector are compared to each other to obtain a signal for setting an emitting wavelength of the laser light source to a desired value; and

said signal is used for controlling a wavelength of the laser light source so that the wavelength is kept to be a given wavelength.

[Claim 4]

Optical-fiber communication equipment comprising at least, a laser light source, a means for changing light of the laser light source to a parallel plane wave to form a parallel light path, an optical system for dividing the parallel plane wave, a wavelength selection means, and a first and a second light detector, wherein:

said wavelength selection means is located in the parallel light path;

said laser light source is a laser light source that is capable of emitting at a plurality of emitting wavelengths;

said wavelength selection means has a plurality of light transmission portions having desired wavelengths existing at given wavelength intervals;

the wavelength interval of the light transmission

portions is equivalent to a channel grid interval of wavelength division multiplexing optical-fiber communication;

one of said plurality of emitting wavelengths of the laser light source is equivalent to an emitting wavelength corresponding to a desired wavelength that is shifted from a wavelength portion having the highest transmittance among said plurality of light transmission portions provided by the wavelength selection means;

said optical system for dividing the parallel plane wave divides the parallel plane wave into at least two pieces of light: light that is transmitted through said wavelength selection means; and light passing through a medium having optical characteristics different from those of the light that is transmitted through said wavelength selection means;

signals based on photocurrents from the first and the second light detector, which receive each of said divided light, are compared to each other to obtain a signal for setting an emitting wavelength of the laser light source to a desired value; and

said signal is used for controlling each of said plurality of emitting wavelengths provided by the laser light source so that each emitting wavelength is kept to be a given wavelength.

[Claim 5]

Optical-fiber communication equipment according to any one of Claims 1, 2, 3, and 4, wherein:

said wavelength selection means is a Fabry Perot type etalon in which:

a refractive index of its medium is within a range of 1.0 to 4.0;

surface reflectivities of both reflection planes of the medium are within a range of 20 to 70%; and

a thickness of the medium is set so that a plurality of light transmission portions are generated at given wavelength intervals, and that any one of the plurality of light transmission portions is equivalent to an emitting wavelength desired by the laser light source.

[Claim 6]

Optical-fiber communication equipment according to any one of Claims 1, 2, 3, 4, and 5, wherein:

said wavelength selection means is a Fabry Perot type etalon constructed of two or more kinds of materials, which differs each other in at least one of temperature characteristics and a refractive index.

[Claim 7]

Optical-fiber communication equipment according to any one of Claims 1, 2, 3, 4, 5, 6, 7, and 8, wherein:

a thickness of said Fabry Perot type etalon, which

depends on a channel grid interval of wavelength division multiplexing optical-fiber communication, is set to a value that is shifted from a free spectral range of the Fabry Perot type etalon, and thereby temperature characteristics of transmission characteristics of the Fabry Perot type etalon is compensated.

[Claim 8]

Optical-fiber communication equipment according to Claim 3 or 4, wherein:

said optical-fiber communication equipment comprises an information storing portion, and said laser light source comprises a temperature detecting means;

the information storing portion stores temperature characteristics of a light transmission portion of the wavelength selection means; and

according to a signal from the temperature detecting means and said stored temperature characteristics of light transmission portion of the wavelength selection means, a shift of an emitting wavelength of the laser light source from a channel-grid wavelength of said wavelength division multiplexing optical-fiber communication is compensated.

[Claim 9]

Optical-fiber communication equipment according to any one of Claims 1, 2, 3, 4, 5, 6, 7, and 8, wherein:

said laser light source is located at a position

that is shifted from an optical axis of the means for
changing light of the laser light source to a parallel
plane wave to form a parallel light path; or a normal line
of an incident edge for said wavelength selection means or
the laser-light dividing means is located so that the
normal line crosses the optical axis of the means for
changing light of the laser light source to a parallel
plane wave to form a parallel light path.

[Claim 10]

An optical system, wherein:

said optical system comprises optical-fiber
communication equipment according to any one of Claims 1, 2,
3, 4, 5, 6, 7, 8, and 9.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Pertains]

The present invention relates to an optical-fiber
transmitter module that is applied to wavelength division
multiplexing optical-fiber communication systems.
Furthermore, the present invention relates to applied
equipment that uses such optical-fiber transmitter module.

[0002]

[Prior Art]

Because optical-fiber communication provides us with
high resistance to electromagnetic noise as well as long-

distance, high-speed, and high-capacity communication, the optical-fiber communication enables us to construct a communication system that ensures high reliability. Conventionally, this system transmits light having one wavelength through one optical fiber. However, with the coming of high-capacity information-oriented society in recent years, higher transmission capacity is required. For this reason, technology of wavelength division multiplexing optical-fiber communication system has been put into practical use. According to the technology, a plurality of light having a different wavelength one another are transmitted through one optical fiber, which permits a number of communication channels to be increased for higher capacity. For wavelengths of light transmitted through an optical fiber, a wavelength region having a low transmission loss for the optical fiber is used. A 1.3 μ - region and a 1.5 μ -region are called 'transmission window'. Because wavelength widths of those windows are limited, narrowing a wavelength interval between channels increases a number of transmission channels. For the present, although a frequency interval is 200 GHz or 100 GHz, the interval tends to become narrower (50 GHz or 25 GHz). If they are expressed in wavelength intervals, they are about 1.6 nm, 0.8 nm, 0.4 nm, and 0.2 nm respectively. If the wavelength interval is narrowed in this manner, it becomes

necessary to keep wavelengths of a laser light source
constant with accuracy. That is because if one of the
wavelengths of the laser light source fluctuates and
overlaps with a wavelength of the next channel, a crosstalk
with the next wavelength channel arises at a receiving end,
which impairs reliable information communication. Those
wavelength channels (or frequencies) are called ITU-TS
(International Telecommunication Union-Telecommunication
Standardization Sector) grid, which is widely known as ITU
recommendation. Additionally, wavelength fluctuations of
the laser light source due to aging must also be prevented.
[0003]

Taking such background into consideration, a method
for controlling wavelengths of a laser light source used
for wavelength division multiplexing optical-fiber
communication has been proposed. As an example of this
method, there is a method called 'wavelength locking'
described in Japanese Patent Laid-Open No. Hei 11-31859
(Japanese Patent Application No. Hei 9-186545). A basic
configuration of this example is shown in Fig. 1. Light
emitted from a diode laser 1 is introduced into a fiber 2,
and then condensed by a lens 3. The condensed laser light
reaches a beam splitter 5 through a first bandpass filter 4.
This laser light is reflected by this beam splitter 5, and
reaches a bandpass filter 8 that uses a wavelength filter,

in other words, a multilayer thin film device of dielectric.
After that, a light detector PD1 receives transmitted light
that has been transmitted through a shoulder slope portion
in transmission characteristics of the bandpass filter. On
the other hand, a light detector PD2 receives reflected
light of the bandpass filter 8. In this example, a
photocurrent difference signal between the light detector
PD1 and the light detector PD2 is treated as a signal for
detecting a wavelength shift. By the way, a reference
number 7 is an optical fiber; a reference number 9 is an
output-ratio calculating means; and a reference number 10
is a wavelength controlling means.

[0004]

This example uses a bandpass filter having a single
transmission peak. However, only one kind of bandpass
filter cannot handle a different wavelength channel. For
this reason, in order to handle the ITU-TS grid wavelength
channel described above, as many bandpass filters having a
different bandpass as a number of channels are required.
Producing those many filters results in complicated
production control, which is not realistic.

[0005]

In addition, as clearly shown in Fig. 1, this
example has the following mechanism: preparing a wavelength
locker module separately from the optical-fiber transmitter

module comprising the laser light source; branching a
portion of light of the optical-fiber transmitter module
and introducing it into the wavelength locker module to
detect a wavelength shift; and giving its feedback to the
laser light source in the optical-fiber transmitter module.
[0006]

In this case, integrating the wavelength locker
module into the laser light source module and building the
wavelength locker module into the laser light source module
enables us to achieve higher cost performance. In addition,
as regards the laser light source module, concurrently
preparing monitoring-light for keeping a fiber output
constant is required.
[0007]

Moreover, an example showing that a wavelength
locking portion is built into a laser module is described
in Japanese Patent Laid-Open No. Hei 10-79723 (Japanese
Patent Application No. Hei 9-186204). Additionally, as
shown in Fig. 2, because an etalon 18 is used as a
wavelength filter, a transmission peak appears repeatedly
in response to an order of multiple interference. Because
of it, one wavelength filter permits a plurality of
wavelength channels to be wavelength-locked. To be more
specific, a parallel plane plate (etalon) 18 is located at
a tilt in a divergent light path from a laser light source

12. Twin light detectors 20 and 22, which are placed immediately behind the parallel plane plate 18, split and receive transmitted light. A photocurrent difference between them is a wavelength-shift detecting signal 28. By the way, in the diagram, a reference number 16 is an optical lens; a reference number 12 is a laser divergent source; and a reference number 14 is a diode laser edge. In this case, each of the light that reaches the twin light detectors 20 and 22 must have a different light path length each other when passing through the etalon. In other words, the etalon requires incidence of divergent light or convergent light. That is because: regarding parallel plane waves, there is no light-path difference, resulting in the same signal; therefore, no difference signal is detected between the twin light detectors. In reality, it is a well-known fact that when an etalon receives incidence of divergent light, finesse (described later) of the etalon decreases effectively. In addition, because the etalon is located at a tilt, a number of multiple reflection at the etalon decreases, causing effective decrease of the finesse. The decrease of the effective finesse lowers a resolution of the etalon, which causes wavelength locking accuracy to be lowered. Moreover, quantity of divergent light that reaches the twin light detectors 20 and 22 decreases, resulting in lower optical efficiency of laser light. In

addition, as regards the laser light source module, concurrently preparing monitoring-light for keeping a fiber output constant is required.

[0008]

The present invention tries to address those problems furthermore.

[0009]

[Problem to be Solved by the Invention]

The present invention provide an optical system and its control system, which lock each emitting wavelength of a laser light source to a specified value. This optical system can be separately operated as a wavelength locker module; it can also be built into an optical-fiber transmitter module comprising a laser light source.

[0010]

As regards wavelength division multiplexing optical-fiber communication systems, communication capacity is inevitably required to be increased by increasing wavelength multiplicity. Under such circumstance, it is strongly required that crosstalk between wavelength channels caused by the narrowband wavelength-channel interval is eliminated. That is to say, as a more specific technology, a device, which detects a wavelength shift of a laser light source to give its feedback to the laser light source and locks laser wavelengths with high accuracy and

with high optical efficiency, is built into a module.
Moreover, wavelength locking is required throughout a broad
wavelength portion corresponding to the ITU-TS grid.
[0011]

As a wavelength filter for detecting the wavelength
shift, there is the Fabry Perot etalon described above.
However, we should make full use of performance of the
etalon from the viewpoints of: resolution of wavelength
selection; optical efficiency; increase in density of
implementation into a laser light source module; mechanical
stability; compensation for a locking-wavelength shift
caused by a change in temperature; and the like.
[0012]

Furthermore, the etalon is a parallel plane plate.
Because of it, when the etalon is placed in parallel
luminous flux, its reflected light returns the laser light
source, which constitutes a second resonator. As a result,
laser mode competition causes fluctuations of a laser
output.
[0013]

The present invention solves the technical problems
described above.
[0014]

[Means for Solving the Problems]

A first typical aspect of the present invention is

optical-fiber communication equipment comprising at least, a laser light source, a means for changing light of the laser light source to a parallel plane wave to form a parallel light path, a wavelength selection means, and a plurality of light detectors, wherein:

said wavelength selection means is located in the parallel light path;

said wavelength selection means has at least two transmission bands;

the parallel plane wave is divided into at least two pieces of light: light that is transmitted through said wavelength selection means of the parallel plane wave; and light that passes through a medium having optical characteristics different from that of the light transmitted through the wavelength selection means;

the plurality of light detecting means detects each of the light; and

a given signal based on a difference signal between photocurrents, which have been output from the plurality of light detecting means, is supplied to said laser light source as feedback.

[0015]

A second typical aspect of the present invention is optical-fiber communication equipment comprising at least, a laser light source, a means for changing light of the

laser light source to a parallel plane wave to form a
parallel light path, a wavelength selection means, and a
plurality of light detectors, wherein:

said wavelength selection means is located in the
parallel light path;

said wavelength selection means has at least two
transmission bands;

the parallel plane wave is divided into at least two
pieces of light: light that is transmitted through said
wavelength selection means of the parallel plane wave; and
light that is not transmitted through said wavelength
selection means;

the plurality of light detecting means detect each
of the light; and

a given signal based on a difference signal between
photocurrents, which have been output from the plurality of
light detecting means, is supplied to said laser light
source as feedback.

[0016]

In the embodiments of the present invention, how
much an emitting wavelength of the laser light source is
shifted from a desired emitting wavelength is detected.
Therefore, by changing the laser light source so that the
difference signal becomes zero or a constant value, it is
possible to eliminate the shift of the emitting wavelength

from the desired emitting wavelength. Also in other aspects and embodiments according to the present invention described below, a method for eliminating an emitting wavelength shift is basically similar to that described above.

[0017]

In the present invention, parallel plane waves are used. Therefore, when taking several measures to detect a wavelength, there is no loss of light, which ensures extremely high optical efficiency. On the other hand, if divergent light is used, light divergence causes a loss of light, resulting in low optical efficiency.

[0018]

In addition, as preferred measures, a change in transmission characteristics of the wavelength selection means due to temperature is compensated. In its typical example, an information storing component is located in optical-fiber communication equipment, and a laser light source has a temperature detecting means. On the other hand, the information storing component stores temperature characteristics of light transmission portion of the wavelength selection means. An emitting wavelength shift of the laser light source from a desired wavelength is compensated according to a signal from the temperature detecting means and the stored temperature characteristics

of the light transmission portion of the wavelength

selection means. This method is extremely useful for

compensating a shift from a channel grid wavelength of

wavelength division multiplexing optical-fiber

communication described later.

[0019]

As regards said division of the parallel plane wave,

a typical example is that both transmitted light and

reflected light of the wavelength selection means are

provided, or that a means for dividing a transmitted

light's light path into a plurality of paths is provided.

Specific dividing methods are described later.

[0020]

Such configuration permits emitting wavelengths of a

laser light source to be fixed with extreme accuracy. This

configuration uses parallel light as described above, which

ensures extremely high optical efficiency. Therefore, it

is possible to achieve extremely high accuracy for its

control.

[0021]

As said laser light source, a diode laser device

having a normal APC (Automatic Power Control) or a diode

laser device having a wavelength controlling means in the

device itself can be used. In the diode laser device

having a wavelength controlling means in the device itself

shown as an example, a local temperature controlling means
(for example, a heater) is located in proximity to a laser
emitting portion, and this temperature control prevents
emitting frequencies of laser emitting from varying. There
is also another example: a refractive index modulation
portion for controlling laser emitting wavelengths is
located in proximity to a laser emitting portion; a local
temperature controlling means (for example, a heater) is
located in proximity to the refractive index modulation
portion; and this temperature control prevents emitting
frequencies of laser emitting from varying. There is also
another example: a current applying means is provided in
this refractive index modulation portion to modulate a
refractive index by injection current. Examples of the
diode laser device having a wavelength control means are
described in detail in description of the preferred
embodiments. In the present invention, the signal based on
a difference signal between the photocurrents is supplied
to the various laser wavelength controlling means as
feedback. Application of the present invention using such
wavelength-variable diode laser device enables control with
higher accuracy and fineness.

[0022]

In addition, generally, the diode laser device has a
means for controlling the device's temperature. The signal

based on a difference signal between the photocurrents can
be supplied to this temperature controlling means as
feedback. This method enables us to realize more stable
emitting as compared with simple feedback to APC described
above. A typical example of the means for controlling
temperature of the diode laser device is for example a
Peltier cooler. The diode laser device is usually put on
the top of this Peltier cooler.

[0023]

As the means for changing light of a laser light
source to a parallel plane wave to form a parallel light
path, general collimator elements including for example
aspherical lens, lens assemble, ball lens, and selfoc lens
can be used with satisfaction. Regarding the parallel
plane wave, it is desirable to have flatness that is ten
times or less a wavelength, taking the object of the
present invention into consideration,

[0024]

As the parallel plane wave, there are light that is
emitted in a direction of information transmission, and
light that is emitted in its opposite direction. The
optical-fiber communication equipment can be configured
using any of the light. Additionally, regarding a
connection from the diode laser device to the means for
forming a parallel light path, light may be directly

introduced into the means, or a desired optical component may be located between them. However, when applying the present invention, in either case, a desired module can be configured as necessary. What is required in the present invention is that light from the diode laser device can be changed to a parallel plane wave.

[0025]

A typical example of said wavelength selection means having at least two transmission bands is a wavelength-selection transmission type filter having a Fabry Perot structure. A typical example of the filter is a Fabry Perot etalon (generally, it is simply called 'etalon' for short; also in the specification of the present invention, hereinafter it is simply referred to as 'etalon'). There are several kinds of Fabry Perot interference type etalons: an etalon of which a physical distance between reflection films is fixed; an etalon of which the distance is variable by PZT driving. In addition, the etalon is also divided into two groups: an etalon in which a material between the reflection films is a gas; and an etalon in which the material is a solid matter. The former is called air space type or air gap type; the latter is called solid type. Basically, the present invention can be applied to any type of the etalon.

[0026]

As a Fabry Perot type etalon, a configuration
described below is extremely useful for fixing a plurality
of wavelengths of a laser light source to given wavelengths.
To be more specific, the following settings are provided: a
refractive index of an etalon medium is within a range of
1.0 to 4.0; surface reflectivities of both reflection
planes of the medium are within a range of 20 to 70%; and a
thickness of the medium is set so that a plurality of light
transmission portions having desired wavelengths are
generated at given wavelength intervals, and that any one
of the plurality of light transmission portions corresponds
to an emitting wavelength desired by the laser light source.
In this connection, although it depends on designs of
members for light detection as a matter of course, for said
surface reflectivities of both reflection planes of the
medium, a range from 20 to 50% is generally advantageous to
error-signal detection. That is because a change in
transmission characteristics of the etalon by a change in
wavelength results in a large portion for use.

[0027]

Using this configuration, the etalon permits all of
a plurality of transmitting wavelengths to be kept a
constant value. Among other things, by matching
transmission characteristics of the etalon with a channel
grid in wavelength division multiplexing optical-

transmission, wavelength stabilization with high accuracy

can be achieved extremely simply and easily. Moreover,

regardless of using a plurality of wavelengths, the etalon

enables easy implementation to a usual module.

[0028]

Furthermore, when associating an emitting wavelength

of the laser light source with the light transmission

portion provided by the wavelength selection means, it is

more desirable to equate the emitting wavelength of the

laser light source to an emitting wavelength corresponding

to a desired wavelength that is shifted from the highest

transmittance wavelength portion in this transmission

portion. This embodiment can be said to be more practical.

That is because if an emitting wavelength of the laser

light source exists in a portion where a relation between a

light wavelength and the transmission characteristics has a

steep gradient, a shift of the emitting wavelength can be

detected more effectively. In other words, this means that

a wavelength resolution is higher than that of other means.

If a relation between a light wavelength and the

transmission characteristics of the wavelength selection

means shows relatively flat characteristics, a change in

photocurrent by a shift of the emitting wavelength is

relatively small.

[0029]

As described above, in the present invention, it is required that the parallel plane wave is divided into at least two pieces of light: light that is transmitted through said wavelength selection means; and light that passes through a medium having optical characteristics different from that of the light transmitted through the wavelength selection means. As the means for passing the parallel plane wave through the medium having optical characteristics different from that of the light transmitted through the wavelength selection means, several methods are considered. In this case, the 'medium having optical characteristics different from that of the light transmitted through the wavelength selection means' means a light path containing a reflector, a light-path dividing means, or a light path in which they are combined, if the medium as the light path is a translucent solid medium, air or gas. What is required is that the light path can obtain light intensity different from that of the light transmitted through the wavelength selection means. By the way, the light path using air as a media means a light path in a general space. If an example of a light-path dividing means described below is allowed for, its meaning can be sufficiently understood.

[0030]

As the light-path dividing means, using a usual

light-path dividing means is sufficient. Its typical
examples are an amplitude-dividing beam splitter and a
wavefront-dividing beam splitter.

[0031]

In addition, for the purpose of dividing the light
path into two or more, several methods are considered.
Their typical examples are listed as below. From a first
to a fifth example are examples in a case where the
amplitude-dividing beam splitter is used as a light-path
dividing means; and a sixth example is an example in a case
where the wavefront-dividing beam splitter is used.

[0032]

The first example is: a light path is divided into
reflected light of said light-path dividing means and
transmitted light of the light-path dividing means; this
transmitted light of the light-path dividing means is
introduced into the wavelength selection means; and then a
difference signal is obtained from transmitted light of the
wavelength selection means and said reflected light of the
light-path dividing means.

[0033]

The second example is: a light path is divided into
reflected light of said light-path dividing means and
transmitted light of the light-path dividing means; this
transmitted light of the light-path dividing means is

introduced into the wavelength selection means; and then a difference signal is obtained from reflected light of the wavelength selection means and said reflected light of the light-path dividing means.

[0034]

The third example is: a light path is divided into transmitted light of said light-path dividing means and reflected light of the light-path dividing means; this reflected light of the light-path dividing means is introduced into the wavelength selection means; and then a difference signal is obtained from transmitted light of the wavelength selection means and said transmitted light of the light-path dividing means.

[0035]

The fourth example is: a light path is divided into transmitted light of said light-path dividing means and reflected light of the light-path dividing means; this reflected light of the light-path dividing means is introduced into the wavelength selection means; and then a difference signal is obtained from reflected light of the wavelength selection means and said transmitted light of the light-path dividing means.

[0036]

The fifth example is: reflected light of said light-path dividing means is introduced into the wavelength

selection means; and then a difference signal is obtained from transmitted light of the wavelength selection means and reflected light of the wavelength selection means.
[0037]

The sixth example is: a wavefront is divided into two; a first portion of this divided wavefront is introduced into the wavelength selection means; and then a difference signal is obtained from transmitted light of the wavelength selection means and light intensity of a second portion of said divided wavefront.
[0038]

The seventh example is: a wavefront is divided into two; a first portion of this divided wavefront is introduced into the wavelength selection means; and then a difference signal is obtained from reflected light of the wavelength selection means and light intensity of a second portion of said divided wavefront.
[0039]

A third typical aspect of the present invention is optical-fiber communication equipment comprising at least, a laser light source, a means for changing light of the laser light source to a parallel plane wave to form a parallel light path, a wavelength selection means, and a plurality of light detectors, wherein:

said wavelength selection means is located in the

parallel light path;

said wavelength selection means has a plurality of light transmission portions existing at given wavelength intervals;

an emitting wavelength of said laser light source is equivalent to one of the light transmission portions provided by the wavelength selection means;

the parallel plane wave is divided into at least two pieces of light: light that is transmitted through said wavelength selection means of the parallel plane wave; and light that passes through a medium having optical characteristics different from that of the light transmitted through the wavelength selection means;

the plurality of light detecting means detects each of the light; and

a given signal based on a difference signal between photocurrents, which have been output from the plurality of light detecting means, is supplied to said laser light source as feedback.

[0040]

Using this embodiment enables the following applications from a new viewpoint. A second main viewpoint of the present invention is a method by which a free spectral range of said wavelength selection means is matched with a channel grid interval of wavelength division

multiplexing optical-fiber communication and then a
wavelength of the laser light source is changed so that
this wavelength is fixed to a desired value of the grid.
An important point of this example is that a free spectral
range of the wavelength selection means can be matched with
a channel grid interval of wavelength division multiplexing
optical-fiber communication. By utilizing this for
wavelength locking of the laser light source, it is
possible to equate an emitting wavelength of the
wavelength-control laser device to a channel grid of
wavelength division multiplexing optical-fiber
communication with higher accuracy and simplicity. By the
way, the method for fixing an emitting wavelength of the
laser light source can be applied in the same manner as
that described in the first embodiment.

[0041]

In addition, for this embodiment, a laser light
source or a diode laser device, which comprises a plurality
of emitting portions that enable emitting with a plurality
of emitting wavelengths, can be used. In this case,
corresponding to each emitting portion, the measures to fix
an emitting wavelength as described above are taken. In
this embodiment, a free spectral range of the wavelength
selection means is matched with a channel grid interval of
wavelength division multiplexing optical-fiber

communication. Therefore, only one wavelength selection means provides measures to fix a plurality of emitting wavelengths. In this embodiment, extremely simply measures are taken.

[0042]

A third main viewpoint of the present invention is: said laser light source is located at a position that is shifted from an optical axis of a means for changing light of the laser light source to a parallel plane wave to form a parallel light path; or a normal line of an incident edge for said wavelength selection means or the laser-light dividing means is located so that the normal line crosses the optical axis of the means for changing light of the laser light source to a parallel plane wave to form a parallel light path.

[0043]

The most typical means for changing a laser light source to a parallel plane wave is a collimator element. If the third viewpoint of the present invention is more specifically described from this standpoint, said laser light source is located at a position that is shifted from an optical axis of the collimator element, or a normal line of an incident edge for each of said wavelength selection means and said laser-light dividing means is slanted off from the optical axis of the collimator element so that

reflected light from each of the optical element edges does not return to the laser light source. Using this embodiment in combination with the first or the second embodiment provides an extremely useful embodiment for practical use.

[0044]

In addition, the optical-fiber communication equipment according to the present invention is a laser device handling extremely stable emitting wavelengths, which is useful for various kinds of optical systems. Among other things, the optical-fiber communication equipment according to the present invention is useful when it is applied to wavelength division multiplexing optical-fiber communication systems.

[0045]

[Mode for Carrying out the Invention]

Before explaining embodiments of the present invention, main embodiments of the present invention are summarized as below. After that, a specific configuration of a Fabry Perot type etalon, which is a main component of the present invention, is described in detail beforehand.

[0046]

A first embodiment of the present invention is optical-fiber communication equipment, wherein:

divergent light, which has been introduced directly

or indirectly from a backward position or a forward
position of a wavelength-variable laser light source or a
light source where a modulator of the wavelength-variable
laser light source is integrated, is changed to a parallel
plane wave having flatness ten times or less as much as a
wavelength to form a parallel light path;

a wavelength filter having at least two or more
transmission peaks is located in said parallel light path;

transmitted light or reflected light of said
wavelength filter is divided by a light-path dividing
means;

said divided light is introduced into a plurality of
light detectors;

shifted quantity of an emitting wavelength of said
laser light source is detected by a difference between
photocurrents passing through each of said light detectors;

a means for controlling a wavelength of the laser
light source is provided so that the difference between the
photocurrents becomes a constant value;

and said laser light source is located at a position
that is shifted from an optical axis of the collimator
element, or a normal line of an incident edge for said
wavelength filter or said laser-light dividing means is
slanted off from the optical axis of the collimator element
so that reflected light from each of the optical element

edges does not return to the laser light source.

[0047]

A second embodiment of the present invention is optical-fiber communication equipment according to the present invention, wherein:

said wavelength filter is a Fabry Perot type etalon; and the light-path dividing means located in the parallel light path is an amplitude-dividing beam splitter. This is a typical example for practical use.

[0048]

A third embodiment of the present invention is optical-fiber communication equipment according to the present invention, wherein:

said optical-fiber communication equipment comprises a means for matching a free spectral range of the Fabry Perot etalon with a channel grid interval of wavelength division multiplexing optical-fiber communication, and for changing a wavelength of the laser light source so that this wavelength is fixed to a given value of the grid.

[0049]

The emitting wavelength of the laser light source has been considered up to this point. A fourth embodiment of the present invention is measures to control a light output of the laser light source. Generally, such light output is monitored by light that is emitted from an edge

opposite to a light output used for information exchange. However, if embodiments shown in the present invention is used, it is advantageous to keep a light output of the laser light source constant so that a photocurrent passing through at least one of the plurality of light detectors or a sum of photocurrents passing through at least two of the light detectors becomes constant.

[0050]

A fourth embodiment of the present invention is optical-fiber communication equipment according to the present invention, wherein:

said wavelength filter is a Fabry Perot etalon having taper of a wavelength level for the laser light source, or a Fabry Perot etalon constructed of two parallel plane plates, which are made from glass materials having a different refractive index each other and are connected together in a direction of a plane; and

said optical-fiber communication equipment comprises a means for:

configuring said wavelength filter so that a light-path difference is generated between parallel plane waves passing through different positions of an incidence plane of the etalon;

dividing transmitted light of the Fabry Perot etalon spatially; and

introducing the divided light into two light detectors respectively.

[0051]

A fifth embodiment of the present invention is optical-fiber communication equipment according to the present invention, wherein:

said Fabry Perot etalon has a structure including at least two transparent plates, by which a product of a refractive index and a length for one transparent plate reverses in sign in temperature coefficient as compared with the product for the other transparent plate; and thereby a change in light-path difference of light, which pass through the Fabry Perot etalon, caused by temperature is decreased.

[0052]

A sixth embodiment of the present invention is optical-fiber communication equipment according to the present invention, wherein:

said optical-fiber communication equipment comprises a means for:

matching a free spectral range of the Fabry Perot etalon with a channel grid interval of wavelength division multiplexing optical-fiber communication;

storing temperature characteristics of transmission peaks of the Fabry Perot etalon into a semiconductor

memory; and

compensating a shift of an emitting wavelength of said wavelength-variable laser light source from a channel wavelength of said wavelength division multiplexing optical-fiber communication by a signal from a temperature detector.

[0053]

A seventh embodiment of the present invention is optical-fiber communication equipment according to the present invention, wherein:

the temperature characteristics of transmission peaks of the Fabry Perot etalon is compensated by setting a thickness of said Fabry Perot etalon, which is determined by a channel grid interval of wavelength division multiplexing optical-fiber communication, to a value that is shifted from a free spectral range.

[0054]

An eighth embodiment of the present invention is optical-fiber communication equipment according to the present invention, wherein:

a portion or all of said laser-wavelength controlling means is built into a laser-light-source module package.

[0055]

A ninth embodiment of the present invention is

optical-fiber communication equipment according to the present invention, wherein:

a plurality of laser light sources having said laser-wavelength controlling means are located in parallel; and said optical-fiber communication equipment comprises a means for combining variable-wavelength portions covered by each laser light source.

[0056]

Next, a specific configuration of a Fabry Perot type etalon is described in detail beforehand. Fig. 3 is a diagram used for explaining a principle of an etalon, which is applied to the present invention. The diagram illustrates a cross section of a basic element and a condition of light. A basic configuration of the etalon is a parallel plane plate having high parallelism as well as high flatness. Between reflection planes, in other words, between translucent films, a gas or a solid matter is placed. To be more specific, the etalon is an optical resonator comprising a pair of opposed layers having a high reflectivity, between which a medium is sandwiched as a spacer. Its specific configuration is, for example, a resonator using a glass substrate as a base, on which each layer of a reflector, a spacer, and a reflector is laminated one by one. Another example is a resonator using a glass substrate as a base; on both sides of the glass

substrate, a reflector layer is formed. The etalon associated with the present invention is a wavelength-selection transmission type filter. It is important for the etalon to have two or more transmission bands. As regards this point, basic characteristics of the etalon are different from those of a bandpass filter using so called a interference-film multilayer filter that is conventionally known.

[0057]

Light, which has been transmitted through this etalon, generates a peak repeatedly for a shift of that wavelength. Light 100, which reaches the etalon at an incident angle θ, is reflected by two surfaces of an etalon 101 repeatedly and many times. In Fig. 3, A1 and A2 exemplify positions of the incident light. In addition, B1 and B2 shown in Fig. 3 exemplify positions through which light T1 and T2 are transmitted. R1 and R2 exemplify reflected light. As a result of interference of many generated wavefronts, the following transmitted light It is obtained:

[0058]

It $= 1/(1 + F \sin^2(\phi))$ $\cdots$ (1)

Where $F = 4R/(1 - R)^2$ $\cdots$ (2), and

$\theta = (2\pi nt/\lambda) \cos \theta'$ $\cdots$ (3)

Moreover, R is a surface reflectivity of each side 1,

2 of the etalon 101; n is a refractive index of the etalon;
t is a thickness of the etalon; λ is a light wavelength;
and θ ' is an angle given by light in the etalon.

[0059]

Here, Snell laws of refraction holds as below.

$\sin\theta = n\sin\theta$ ' $\cdots$ (4)

[0060]

Fig. 3B is a graph of the formula (1) using surface
reflectivity R as a parameter. In Fig. 3B, a vertical axis
is intensity of transmitted light (arbitrary unit), and a
horizontal axis is phase difference. This phase difference
is expressed in $2\pi(nt/\lambda)\cos(\theta/n)$.

[0061]

At this point, finesse Φ is defined as a parameter
that expresses sharpness of resonance of an etalon.

[0062]

$\Phi = (\pi\sqrt{F})/2$ $\cdots$ (5)

In addition, an interval between repeated peaks is called
FSR (Free Spectral Range).

[0063]

As a wavelength range: FSR = $\lambda^2/2nt$ $\cdots$ (6)

As a frequency range: FSR = c/2nt $\cdots$ (7) (where c is speed
of light)

[0064]

There is the following relation between finesse Φ

and FSR:

[0065]

$\Phi = FSR/\varepsilon \cdots (8)$

where ε is a half-width of a transmission peak.

[0066]

Therefore, designing a etalon's thickness t, a refractive index n, and surface reflectivity R permits FSR to match with ITU-TS grid.

[0067]

Matching FSR with ITU-TS grid enables us to detect an wavelength error by selection characteristics having desired sharpness over a wide wavelength range.

[0068]

For this purpose, in particular, the following ranges are often used: a refractive index of an etalon's medium ranging from 1.0 to 4.0; and surface reflectivities of both reflection planes of said medium ranging from 20 to 70%. Moreover, determining a thickness of said medium by t = c/(2n·FSR) enables us to obtain an etalon of which FSR corresponds to ITU-TS grid. In this manner, generating a plurality of light transmission portions having desired wavelengths at given wavelength intervals permits any one of the plurality of light transmission portions to be equivalent to an emitting wavelength desired by the laser light source. By the way, a thickness of an etalon's

medium often ranges approximately from 0,1 mm to 10 mm. As mentioned above, a range of surface reflectivity from 20 to 50% is more practical.

[0069]

A second factor constituting a problem solving means of the present invention is a laser light source. As is the case with a diode laser for example, a wavelength of a laser light source can be changed by changing a driving current or an operation temperature. Fig. 4 is a diagram illustrating an example of a relation between temperature and emitting wavelength regarding a diode laser. This laser's emitting wavelength corresponds to the ITU-T grid described above. A vertical axis is indicated as the ITU-T grid for this purpose. As regards a general diode laser, increase in temperature by $1^{\circ}C$ changes a wavelength by 0.1 nm as shown in Fig. 4. In the present invention, a laser light source like this, which is capable of changing an emitting wavelength, is used. As a laser light source, divergent light from a backward position or a forward position of a laser light source, where a modulator for modulating its emitting intensity is integrated, may be directly used; or divergent light, which has been introduced indirectly from the light source after passing through optical waveguides such as a fiber, a modulator, and a switch, may be used.

[0070]

Fig. 5 shows a basic configuration of a problem

solving means according to the present invention. To be

more specific, divergent light from a laser light source

100 such as the various laser light sources described above

is condensed by a collimator 102, such as a lens, and an

element comprising a diffraction grating, to form a light

path 103 as a parallel plane wave. Flatness of the

obtained parallel plane wave must be at a maximum ten times

or less as much as a wavelength on a wave aberration basis.

A light-path dividing element 104, which is a component of

the present invention, is located in a parallel luminous

flux 103 obtained in this manner. In its branched light, a

light detector 115 is located to monitor a light output

from the laser light source 100.

[0071]

On the other hand, a wavelength filter 106 such as

an etalon, which has two or more transmission peaks

periodically, is located in transmitted light 105 of the

light-path dividing element 104. A light detector 109 is

placed behind the wavelength filter 106 to receive light

107 of which a wavelength is selected. An error signal is

generated by a difference between a photocurrent Pm

supplied to the light detector 115 for monitoring a light

output and a photocurrent Pt that is supplied according to

the formula (1) to the light detector 109 for monitoring a wavelength placed behind the etalon 106. A given signal is supplied to the laser light source 100 as feedback so that this value becomes zero or a constant value.

[0072]

That is to say, the error signal $A(\lambda)$ is expressed in the following formula:

$A(\lambda) = Pt - pm \cdots (9)$

[0073]

Fig. 6 illustrates the formula (9). A horizontal axis is wavelength difference, and a vertical axis is error signal (arbitrary unit). This is an example showing that an optical system for wavelength locking is located in front (a fiber side).

[0074]

As an error signal, the following signal, which is normalized by light quantity, can also be used:

$A(\lambda) = (Pt - Pm)/(Pt + Pm) \cdots (10)$

Additionally, in the present invention, as described later, a difference between reflected light and transmitted light from the etalon 106 can also be used as an error signal. Moreover, in actual signal processing, if a difference signal is obtained from both signals based on the photocurrents, obtaining the difference signal by multiplying either or both of the signals by a desired

coefficient is also taken into consideration. For example, when transmitted light PD1 and reflected light PD2 are compared, a difference signal is defined as PD1 − α PD2, which is kept to be zero or a given value.

[0075]

Concerning the locations described above, when the reflected light from surfaces of the light-path dividing element 104 and the etalon 106 return to the laser light source 100, a second resonator for the diode laser is formed outside, which causes a problem of laser output fluctuations.

[0076]

That is to say, Fig. 7 shows a relation between a resonator 190 of the diode laser itself and a mirror 191 located outside of the resonator 190. In Fig. 7, both reflection plates of the resonator 190 are schematically illustrated as 190-1 and 190-2. An upper portion of Fig. 7 shows a relation between this resonator and the mirror, and a lower portion shows an emitting condition. If the outside mirror 191 exists, an outside resonator mode 193 is newly generated between a diode-laser emitting mode 192 and the mirror 191. Because these modes are within a range of a gain curve 194 of the diode laser, laser emitting may occur. This results in laser mode competition among many modes, causing the laser output fluctuations. The

fluctuations is noise that is called feed back noise.

[0077]

Typical measures to solve this problem is a method as described below. To be more specific, a laser light source is located at a position that is shifted from an optical axis of a means for changing light of the laser light source to a parallel plane wave to form a parallel light path; or a normal line of an incident edge for said wavelength selection means or the laser-light dividing means is located so that the normal line crosses the optical axis of the means for changing light of the laser light source to a parallel plane wave to form a parallel light path.

[0078]

As a first example, the laser light source 100 is located at a position that is shifted from an optical axis 197 of a collimator lens 196 as shown in Fig. 8A. This permits reflected feedback light from a reflecting surface 198 of the light detector to be focused on an opposite side 199 of the optical axis. Thus, the reflected light does not return to the laser light source 100. If a focal distance of the collimator lens 196 is f and an emitting size of laser is a, the laser light source is placed at a position that is shifted from the optical axis 197 of the collimator lens 196 by an angle θ. In this case, the angle

θ is determined by keeping a relation of f θ > a. As a result of it, the reflected light from the reflecting surface 198 is condensed at a position 199.

[0079]

A second example is a method in which a normal line of the reflecting surface 198 of the etalon or the light detector crosses the optical axis 197 of the collimator 196 at an angle θ as shown in Fig. 8B. This prevents reflected feedback light from returning to the laser light source 100. As described above, the angle θ may be determined in a manner similar to that of the first example. As a result of it, the reflected light from the reflecting surface 198 is condensed at a position 199.

[0080]

In addition, as another means of the present invention, the following means can be used: placing a Fabry Perot etalon having slight taper into the parallel luminous flux; and receiving light using two light detectors that are placed immediately behind the Fabry Perot etalon. Fig. 17 shows a specific example of this method.

[0081]

In the case of Fig. 17, a thickness of an etalon 701 varies. Although this example is provided for the purpose of addressing a problem described later, the example addresses the problem of reflected light explained here at

the same time. Concerning parallel light from a diode
laser source, reflected light from an inclined surface of
the etalon does not return to the diode-laser light source
as a matter of course. The taper is required to be
provided to such an extent that the reflected light does
not return to an emitting spot of the laser light source.
In this connection, there was an example of a conventional
configuration in which an etalon with a shape of a parallel
plate is located in a direction where the etalon is
inclined at a certain angle. However, in this example, the
etalon 701 has taper at least on one surface. As a matter
of course, both surfaces may be provided with taper. As
measures against reflected light, this example enables
extremely easy optical adjustment as compared with the
conventional example described above, and is practical. In
other words, if the parallel-plate shaped etalon is
inclined at a tilt angle from the laser light source having
divergent light, it is required to adjust two angles: a
tilt angle of the parallel-plate shaped etalon; and a
divergent angle of laser light. In this example, however,
laser light is parallel and at the same time a taper angle
of the etalon is fixed. This enables us to obtain a laser
module having few adjustment points and high accuracy at
the time of device implementation.

    As described above, this example enables operation

as below. Using the etalon with taper causes a slight
shift of a selected wavelength if a position through which
light passes is different. When the wavelength of the
laser light source is shifted, a photocurrent peak of each
light detector is also shifted. Therefore, an error signal
of a wavelength shift is obtained by determining a
deference between both photocurrents. Another means can
also be used: instead of the taper etalon, connecting two
kinds of plane plates, which have a different refractive
index each other, together on edges; and generating a
light-path difference of light passing through each portion
of the plane plates. Because a photocurrent peak of each
light detector is shifted when a wavelength of the laser
light source is shifted, this means enables us to obtain an
error signal of the wavelength shift in a similar manner by
determining deference between both photocurrents.
[0082]

In this connection, if a wavelength of the laser
light source is changed by temperature, a temperature of
the etalon may also changes. In this case, the following
problem arises: thermal expansion of the etalon or a change
in refractive index due to temperature fluctuates a light-
path length nt; and it causes a transmission peak
wavelength to be shifted, resulting in a shift from a given
ITU-TS grid. In order to solve this problem, dividing the

etalon to use the divided etalon in combination with a material, of which temperature fluctuation of a light-path difference is negative, provides a means that prevents a transmission peak of the etalon from shifting even when temperature is changed. In addition, storing temperature characteristics of the etalon into a semiconductor memory provides a means for locking a wavelength at a value that is compensated for each operation temperature. Moreover, creating an etalon in such a manner that its thickness t is slightly changed to permits FSR to be shifted from ITU-TU grid provides a method for compensating a transmission peak due to a change in temperature.

[0083]

Furthermore, because a wavelength-locking optical system according to the present invention enables compact design, the optical system can be built into an optical-fiber transmitter module comprising a laser light source. Additionally, it is possible to prepare a light source for a high-capacity wavelength division multiplexing optical communication system, which is capable of locking and fixing a wavelength throughout a range of a wavelength portion wider than that of a single laser light source, by: aligning a plurality of laser light sources, of which a wavelength-variable portion is continuously linked one another, in parallel; and locating the wavelength-locking

optical system according to the present invention before a position where light from the plurality of laser light sources are gathered into one fiber by a wavelength multiplexer.

[0084]

As described above, using a configuration comprising basic elements according to the present invention as a means for solving the problems enables us to exploit the full performance of the etalon. That is to say, the technical problems are solved, which could not be conventionally overcome from the viewpoints of: resolution of wavelength selection; optical efficiency; increase in density of implementation into a laser light source module; mechanical stability; compensation for a locking-wavelength shift caused by a change in temperature; and the like.

[0085]

Fig. 9 is a schematic diagram of a main portion illustrating the first embodiment of the present invention. Fig. 9′ shows a portion for detecting a wavelength shift of a light-source's emitting wavelength. Fig. 10 shows an example of a specific configuration for controlling the light-source's emitting wavelength according to a result of the detection.

[0086]

A wavelength-variable light source 100 is, for

example, a DFB (Distributed Feed Back) type or a Fabry

Perot type diode laser. As another example, the

wavelength-variable light source 100 is a light source in

which an electric-absorption type modulator is integrated

into DFB type diode laser. In such wavelength-variable

laser light source 100, an emitting wavelength λ changes in

response to a change in operation temperature T. Because

of it, the wavelength-variable diode laser device like this

is capable of selecting a wavelength corresponding to ITU-

TS grid by controlling operation temperature.

[0087]

This example shows detection of an emitting

wavelength shift of a laser light source by: dividing a

light path of laser light; transmitting one of the piece of

light through an etalon; and measuring both intensities of

light transmitted through the etalon and light that is not

transmitted through the etalon.

[0088]

Light for information exchange 112 of the

wavelength-variable laser light source 100 is collimated by

collimator 111, and combined into an optical fiber 114

through an optical isolator 112 and a focus lens 113.

Generally, this light is called front emitted light of the

wavelength-variable laser light source 100.

[0089]

A configuration of an optical system for wavelength locking is described as below. To be more specific, light on the opposite side of the light for information exchange 112 of the wavelength-variable laser light source 100 forms parallel light 103 by means of a collimator 102. This parallel light has flatness that is at a maximum ten times or less as much as a wavelength on a wave aberration basis. Generally, the light on the opposite side of said light for information exchange is called back emitted light of the wavelength-variable laser light source 100. The parallel light 103, which has been obtained in this manner, is divided into transmitted light 105 and reflected light 116 by a light-path splitter 104. As the light-path splitter 104, there is, for example, a light-path splitter having a configuration in which triangle prisms are connected together, or a light-path splitter having a configuration in which a dielectric thin film is coated on a thin parallel plane plate in the case no adhesive is used.
[0090]

The transmitted light 105 further reaches an etalon 106. As a result, each of light, which has been multiple-reflected inside the etalon, interferes one another, which produces a transmission peak expressed in the formula (1). This transmission peak appears repeatedly in response to a change in wavelength. A specific example of this change is

exemplified in Fig. 3B. A peak interval of the transmitted light is called Free Spectral Range (its abbreviation is FSR) as described above, and expressed in said formula (6) and (7). Transmitted light 107 obtained in this manner is received by a light detector 109 and then is converted into photocurrent. On the other hand, the reflected light 116 of the light-path splitter 104 is received by a light detector 115 and then is converted into photocurrent.

[0091]

As a desired wavelength-error detecting signal, as described above, an error signal $A(\lambda)$ is generated by a difference between a photocurrent passing through the light detector 115 for monitoring a light output and a photocurrent passing through the light detector 109 for monitoring a wavelength that is placed behind the etalon 106.

[0092]

The error signal $A(\lambda)$ is expressed in the following formula:

$$A(\lambda) = Pt - Pm \cdots (9)$$

[0093]

In this connection, the following signal, which is normalized by light quantity, can also be used as an error signal:

$$A(\lambda) = (Pt - Pm)/(Pt + Pm) \cdots (10)$$

[0094]

In this case, intensity of light, which is transmitted through the etalon, can be expressed in the formula (1) as described above.

[0095]

Fig. 6 illustrates the formula (9). In Fig. 6, a horizontal axis is wavelength difference (nm), and a vertical axis is error signal (arbitrary unit). Etalon's reflectivity R is used as a parameter for each curve. In other words, this is a specific example when the etalon's reflectivities are 27, 35, 50, and 65%. However, in any of the reflectivities, an error signal has a periodical peak in characteristics in response to wavelength difference.

[0096]

Here, as described above, a ratio of a half-width of the etalon's transmission peak ε to FSR is called finesse Φ. There is the following relations between the finesse Φ and the reflectivity R:

$F = 4R/(1 - R)^2 \cdots (2)$

$\Phi = (\pi\sqrt{F})/2 \cdots (5)$

$\Phi = FSR/\varepsilon \cdots (8)$

Therefore, in order to obtain a sharp spectral characteristics ε of the etalon, it is required that reflectivities of both surfaces of the etalon is high, and that reflections on both surfaces are caused many times

repeatedly. For this purpose, an angle of incident light to the etalon is required to be in close proximity to vertical. If the incident angle is not vertical, each reflection of reflected light causes a shift. As a result, interference occurs only in a portion of a wavefront, which reduces an effective finesse. As this incident angle, an angle within about 5 degrees is used.

[0097]

In this connection, surface reflectivity of the etalon is set taking a relation between implementation accuracy of the etalon and a ratio of a change in reflectivity into consideration. As it is found out from a diagram showing an example of characteristics, the higher the surface reflectivity becomes, the larger a difference signal becomes in response to a change in wavelength.

[0098]

In addition, because it is required to take reflected light from the etalon to introduce it into a light detector, the light-path splitter 104 is basically necessary. This is an important point of the present invention.

[0099]

Wavelength control using the wavelength error signal having high sensitivity, which has been obtained in this manner, is performed as below.

[0100]

Fig. 10 shows an example of a specific configuration for controlling an emitting wavelength of a light source. In this connection, in Fig. 10, various kinds of members for detecting an emitting wavelength shift of the light source described above are omitted. Only an etalon 106, and two light detectors 109, 115 are simply illustrated. Moreover, a configuration of information exchange side is also omitted in Fig. 10. By the way, L exemplifies a collimator. It may be understood that specific configuration of a laser-light wavelength control module according to the present invention is configured by Fig. 9 and Fig. 10 in combination. Additionally, regarding APC (Automatic Power Control) for keeping a diode-laser output constant, a general method is used. To be more specific, by this method, an output of the light detector 115 is compared with a given fixed value, and a result of the comparison is supplied to a driving-current control circuit 404 of a diode laser 100 as feedback.

[0101]

A parallel plane wave obtained from the laser light source 100 is introduced into the light-path splitter 104, and reflected light is received by the light detector 115. Transmitted light 104 is multiple-reflected off the etalon 106, and passes through the etalon 106. Then, the

transmitted light 104 having light quantity, which is determined by the formula (1) in response to a change in wavelength, reaches the light detector 109. A wavelength error signal is a difference between an output of the light detector 115 and an output of the light detector 109, which is determined by the formula (9) or (10) described above. A wavelength of the laser light source 100 is controlled so that the error signal value $A(\lambda)$ becomes zero or a constant value. As a specific method of this wavelength control, a given signal based on the error signal value is supplied to a driving circuit 402 of said temperature control element 401 as feedback according to the purpose described above. In this connection, a signal, which has been generated by the light detector 115 by detecting reflected light 104, is returned to the driving means 404 of the laser light source as feedback, and thereby emission intensity of laser is controlled.

[0102]

When the error signal is not zero or a given value but a positive value, temperature of the temperature control element is increased. As the temperature increases, an emitting wavelength of the laser device also increases. An example of a relation between this temperature and the emitting wavelength of the laser is shown in Fig. 4. As the emitting wavelength increases, the error signal

decreases. Then, the wavelength is fixed to a value at which this error signal reaches zero or a given value. When the error signal is a negative value, temperature of the temperature control element is decreased. Then, using a change opposite to the temperature increase described above, the wavelength is fixed to a value at which this error signal reaches zero or a given value. Concerning such electrical-signal processing system, a general method is sufficient. As another embodiment, a difference between reflected light and transmitted light from the etalon 106 can also be used as an error signal.

[0103]

Fig. 11 shows an example like this. A beam splitter 104 is located so that a light detector 110 can detect reflected light 108 from an etalon 106. Others are configured basically in the same manner as the example shown in Fig. 9. Therefore, detailed description is omitted. In Fig. 11, the same members as those shown in Fig. 9 are provided with the same reference numbers.

[0104]

As shown in Fig. 12, the reflected light 108 from the etalon 106 is complementary to transmitted light 107, and decreases or increases as the transmitted light increases or decreases. An error signal corresponding to a wavelength shift can be obtained from a difference between

transmitted-light current obtained from a light detector 109 and reflected-light current obtained from the light detector 110.

[0105]

Fig. 12 is a diagram illustrating a relation between reflected light and phase difference regarding the etalon. A horizontal axis is phase difference, and a vertical axis is intensity of reflected light (arbitrary unit). The phase difference is the same as that described in Fig. 3 (b). Reflection-film reflectivity of the etalon is used as a parameter.

[0106]

Fig. 13 is a diagram illustrating a relation between transmitted light (and reflected light) and phase difference when reflectivity of the etalon is 35%. In Fig. 13, a transmitted-light signal is expressed as PD1, and a reflected-light signal is expressed as PD2. A wavelength to be locked is shown by an arrow in Fig. 13. Determining a difference between the transmitted-light signal PD1 and the reflected-light signal PD2 enables us to find out a shift of this maximum wavelength from the locking wavelength more clearly. As shown in this example, when associating an emitting wavelength of the laser light source with the light transmission portion provided by a wavelength selection means, it is equated to an emitting

wavelength corresponding to a desired wavelength that is shifted from the highest transmittance wavelength portion in this transmission portion. As shown in this example, the locking wavelength is set to a portion where a gradient of characteristics curve is slightly steeper than that of a peak wavelength in relation to transmission characteristics or reflection characteristics. Setting the locking wavelength to the portion like this provides more accurate wavelength control.

[0107]

In this embodiment, feedback on operation temperature is given to the laser light source 100 so that an error signal's value corresponding to the wavelength shift is kept constant. This method permits the error signal corresponding to wavelength fluctuation to become double as compared with the first embodiment.

In addition, as is the case with the preceding example, in an optical-fiber communication method using an optical-fiber transmitter module, it is required to keep an optical-fiber output of the optical-fiber transmitter module constant. For this reason, an optical output from the laser light source 101 should be monitored for the purpose of supplying its feedback to a driving power supply. One example of this method is, for example, that photocurrent obtained by introducing reflected light from a

light-path splitter 104 into a light detector 115 is used

for output monitoring as shown in Fig. 11. The optical

output of the laser light source is controlled in response

to this monitored photocurrent signal, while allowing for a

predetermined value. This method uses the same optical-

output control method as that of a general diode laser

device. Moreover, as another optical-output control method,

each of photocurrents from the light detector 109 and the

light detector 110 or a sum of the photocurrents can also

be used for output monitoring. Originally, those

photocurrents are generated by dividing light from the

laser light source simply. Therefore, as a matter of

course, this method can be applied to the photocurrents.

[0108]

Fig. 14 is a diagram illustrating another control

system. In Fig. 14, the same members as those shown in Fig.

10 are provided with the same reference numbers. Therefore,

detailed description is omitted. In this example, the

wavelength-control optical system shown in Fig. 11, for

example, the light-path dividing means 104, the etalon 106,

and the light detector 109, 110 are located in relation to

the laser light source 101. Transmitted light from the

etalon 106 is detected by the light detector 109, and

reflected light from the etalon 106 is detected by the

light detector 110. As a result, an error signal 302 is

obtained. This error signal is based on a predetermined

fixed value, and is supplied to the driving circuit 402 of

the temperature control means 401 of the laser light source

101. A method for controlling and fixing an emitting

wavelength of the laser light source according to this

error signal is similar to that described above.

[0109]

Fig. 15 shows another configuration example of the

optical system for wavelength locking according to the

present invention. Here, only the optical system for

wavelength locking is shown. In this example, as opposed

to the configuration shown in Fig. 5, transmitted light

from the beam splitter 104 is used for optical output

monitoring 115. In addition, reflected light from the beam

splitter 104 is introduced into the etalon 106, and its

transmitted light is received by the light detector 109. A

wavelength error signal is a difference between

photocurrents passing through the light detector 109 and

the light detector 115. As another method, reflected light

from the etalon 106 is passed through the beam splitter 104,

and received by the light detector 110; a difference

between photocurrents passing through the light detectors

109 and 110 is used as a wavelength error signal. A

circuit loop of electrical control-signal processing is the

same as those described in Fig. 10 and Fig. 14. In Fig. 15,

reference numbers 102 and 111 are collimators.

[0110]

Fig. 16 shows another configuration example of the optical system for wavelength locking according to the present invention. Here, only the optical system for wavelength locking is shown. A portion of parallel light, which has been collimated by a collimator ahead of the laser light source 101 (for example, a collimator lens 111), is reflected by a beam splitter 601 and introduced into the etalon 106. After that, its transmitted light is received by the light detector 109. Reflected light from the etalon 106 passes through the beam splitter 601, and then is received by the light detector 110. As optical output monitoring, the light detector 115 placed behind the laser light source 101 can be used. A loop of electrical control-signal processing similar to that described in Fig. 10 or Fig. 14 can be used.

[0111]

Fig. 17 shows another embodiment of the optical system for wavelength locking according to the present invention. To be more specific, light emitted from behind the laser light source 101 is collimated using a collimator lens to form a parallel plane wave. In its light path, an etalon 701 is placed. Twin light detectors 702 and 703, which are placed in close proximity to each other, are

located immediately after the etalon 701. In this case,
light arriving at the light detector 702 differs from light
arriving at the light detector 703 in a position where each
light passes through the etalon 701. In addition, because
the etalon 701 has taper, there arises a shift in a peak
position in response to a change in wavelength of each
transmitted light. Therefore, a wavelength error signal as
shown in Fig. 18 is obtained from a difference between
photocurrents from the light detectors 702 and 703. In
other words, Fig. 18 shows a relation between phase
difference and intensity of transmitted light. A
horizontal axis is phase difference, and a vertical axis is
intensity of transmitted light. A curve shown as circuit 1
is an output PD1 from the light detector 702 that detects
light transmitted through a thin-film portion of the etalon
701. A curve shown as circuit 2 is an output PD2 from the
light detector 703 that detects light transmitted through a
thick-film portion of the etalon 701. As output monitoring,
a sum of the photocurrents PD1 and PD2 from the light
detectors 702 and 703, or photocurrent from the light
detector 115 that receives light ahead of the laser light
source 101 can be used. As a loop of electrical control-
signal processing, a loop similar to that described in Fig.
14 can be used.

[0112]

Fig. 19 shows another embodiment according to the present invention. In this example, an etalon comprises two portions 901 and 902 having different transmission characteristics each other. Light arriving at the light detector 702 differs from light arriving at the light detector 703 in light-path length at the position where each light passes through the etalon. A difference between the light-path lengths can be obtained by changing a refractive index or a mechanical length of the etalon slightly. If the etalon like this is used, an operation principle of wavelength locking is similar to that described in Fig. 14. By the way, in Fig. 19, a reference number 601 is a light-path dividing means, and 115 is a light detector. This system provides light output control of laser.

[0113]

As described above, it is desirable that an emitting wavelength of a diode laser is variable to permit it to be matched with channels of wavelength division multiplexing optical-fiber communication (that is to say, ITU-TS grid intervals including 100, 50, and 25 GHz).

[0114]

In response to this requirement, in the present invention, FRS of the etalon is matched with channels of wavelength division multiplexing optical-fiber

communication (that is to say, ITU-TS grid intervals
including 100, 50, and 25 GHz). To be more specific, a
transmission-peak interval of the etalon is matched with
the ITU-TS grid. Additionally, a wavelength of the laser
light source is locked at an arbitrary wavelength on the
grid. For example, if a solid etalon using fused quartz
having a refractive index n (about 1.4) as its material is
used, a thickness t is calculated by the formula (7)
described above. A change in wavelength of the laser light
source is, for example, practically controlled by changing
a laser temperature using a temperature-variable element
such as a Peltier cooler as a means. An example of a
relation between emitting wavelength and temperature at the
time of laser emitting is similar to that shown in Fig. 4
described above.

[0115]

Next, another example of a laser device
characterized by a variable emitting wavelength is
exemplified. Fig. 20 shows a schematic plane configuration
of the exemplified laser device like this. In this example,
there is a wavelength-variable laser light source 100. Its
temperature is changed by a film heater 151 that is
integrated in proximity to a DFB laser portion 150. The
change in temperature causes a refractive index and a band
gap to be changed, which permits an emitting wavelength of

laser to be variable. Using such wavelength-variable light source in combination with a wavelength locking method according to the present invention provides us with a following effect. To be more specific, when changing a temperature of the laser light source so that emitting is performed at an arbitrary wavelength of ITU-TS grid, only a portion in proximity to a laser activation layer is locally changed in temperature while a temperature of the etalon placed at a position sufficiently far from the layer is little changed. That is because of temperature characteristics of the etalon. When a transmission peak is shifted, a different operation temperature causes a shift from ITU-TS grid. However, if a structure capable of changing only a diode laser's temperature locally is provided like this example, it is not necessary to be concerned about temperature characteristics of the etalon.

Supplemental description of the wavelength-variable diode laser device is given as bellow. As described above, Fig. 20 shows a plane configuration including main components of the wavelength-variable diode laser device. On a semiconductor substrate surface 101, a diode-laser luminous portion 1150 is located. A temperature-variable means 151 is located in proximity to the diode-laser luminous portion 1150. Facing to face with the diode-laser luminous portion 1150, a light modulator 153 is located.

This light modulator 153 is controlled by an electrode 154. Generally, light on this modulator side is used for information communication.

[0116]

A basic configuration of such wavelength-variable diode laser device is a combination of a wavelength-variable light source (or an integrated multiple-wavelength light source) and the light modulator. As an optically combined form of them, it is possible to use any of the following forms: a form that configures each of them separately (Hybrid integration); and a form that integrates them monolithically (monolithic integration). In the device like this, a portion of output light from the wavelength-variable light source or the integrated multiple-wavelength light source is introduced into the light modulator, which generates a light signal by its on/off operation.

[0117]

The laser module according to the present invention is devised to fix an emitting wavelength of laser. However, practically, when fixing a wavelength of the diode laser device having a light modulator, characteristics of the light modulator is also required to be adjusted corresponding to a slight change in wavelength.

[0118]

For the purpose of addressing this problem, the following is taken into consideration: a means for controlling a light modulator's temperature locally is provided in proximity of the light modulator. This temperature-control means controls a temperature of an active waveguide layer of the light modulator to a desired value. Such basic form enables the following: controlling a wavelength of the light source; providing a light-modulation means that corresponds to high-speed light modulation; and controlling chirping characteristics of a light modulator portion; and the like.

[0119]

A first example of specific operation is: in response to fluctuations in wavelength of a light signal introduced into a light modulator, a band gap wavelength of the light modulator is fluctuated to the same extent as the fluctuations. If a more specific embodiment is exemplified, this temperature-control means comprises at least a means for detecting a wavelength of incident light arriving at a light modulator, and a means for adjusting an operation temperature of the light modulator according to the detected wavelength. Practically, in addition to them, this temperature-control means further comprises a means for adjusting an operation current of a diode-laser element portion according to the detected wavelength. Said means

for adjusting an operation temperature of the light

modulator is: in response to fluctuations in wavelength of

a light signal introduced into the light modulator, a band

gap wavelength of the light modulator is fluctuated to the

same extent as the fluctuations. For example, when an

optical signal introduced into the light modulator becomes

long, a band gap wavelength of the light modulator is also

changed to be longer to the same extent as the optical

signal. Adjusting the operation current of the diode-laser

element portion permits slight fluctuations in emitting

power according to the wavelength fluctuations to be

adjusted. In this manner, it is possible to ensure high-

speed light modulation that corresponds to wavelength

control of a light source.

[0120]

A more specific embodiment of a laser module

comprising such wavelength-variable diode-laser device is

described later.

[0121]

Next, a configuration of an etalon, of which a

temperature coefficient is made zero, is exemplified as

below. Fig. 21 is a sectional view illustrating an example

of such etalon. This example shows a method for

constructing an etalon, of which a temperature coefficient

becomes zero effectively, by connecting together two or

more materials characterized in that a temperature

coefficient (a product of refractive index n and length t)

for one material reverses in sign as compared with the

other. To be more specific, assuming that a refractive

index of glass substrates 161 and 162 is n_1, a sum of

lengths of the glass substrates 161 and 162 is t_1, a

refractive index of another material is n_2, and its length

is t_2, materials of the etalon are selected so that a

differential coefficient under temperature becomes zero:

that is to say, d $(n_1 t_1 + n_2 t_2)/dT = 0$ $\cdots$ (11). For example,

regarding silicon gel 163, because a temperature

coefficient of a light-path length is negative, combined

use with a general glass can satisfy the formula (11).

[0122]

If a variable laser-wavelength is provided by means

of the method explained in Fig. 4, a temperature of the

laser is changed in accordance with a temperature of the

etalon because the laser and the etalon are located on the

same Peltier cooler. On the other hand, a transmission

peak of the etalon expressed in the formulas (1), (2), and

(3) is determined by a product of mechanical length t and

refractive index n, that is, a light-path length. However,

the refractive index n depends on temperature, and the

mechanical length t is changed by thermal expansion. As a

result, a transmission peak wavelength has a temperature

coefficient. Even if FSR is matched with a grid interval,
operation of the etalon in a different temperature causes a
shift from the ITU-TS grid 160. This embodiment provides a
means for solving this problem.

[0123]

Fig. 22 is a diagram illustrating another means for
solving the problem of the shift described above. A
horizontal axis is phase difference (relative wavelength
difference), and a vertical axis is intensity of
transmitted light (arbitrary unit). What curves T1 and T2
mean are similar to those exemplified in Fig. 18.

[0124]

A method of this example is described as below. To
be more specific, as shown in the formula (7), a thickness
of the etalon is generally determined so that a free
spectral range of the Fabry Perot etalon is matched with a
channel grid interval of wavelength division multiplexing
optical-fiber communication. However, in this example, a
thick etalon is provided to give a narrow free spectral
range beforehand like a phase-difference range 890 shown in
Fig. 22. At this point, when increasing a temperature of a
laser's temperature control element to operate at the next
grid wavelength, thermal characteristics of the etalon
causes a transmission peak to be shifted to the long
wavelength side. A thickness of the etalon is increased so

that this shifted quantity 891 becomes equal to a difference between the narrowed FSR 890 and the grid interval 892. Thus, the shift due to the etalon's temperature characteristics can be compensated. In this connection, signals of circuit 1 and circuit 2 are similar to those shown in Fig. 18.

[0125]

Fig. 23 shows a method for configuring a device that compensates an error based on a temperature coefficient of the etalon. In other words, this is a method used in a case where the temperature coefficient of the etalon cannot be neglected and causes a shift of a laser's emitting wavelength from an ITU-TS grid.

[0126]

Fig. 23 is similar in basic configuration to Fig. 14. Accordingly, members similar to those shown in Fig. 14 are provided with the same reference numbers. A temperature of a diode laser device 100 is generally controlled by a Peltier cooler 401. To be more specific, an operation temperature of the laser light source 100 is compensated to control the Peltier cooler 401 by a driving circuit 402. In this manner, an emitting wavelength of the diode laser device is controlled.

[0127]

In this example, a temperature detecting means 403

(for example, a thermistor) is provided in proximity to this diode laser device 100. In addition, an information storing means 170 (for example, a semiconductor storing device) is located in the optical-fiber communication equipment. In this information storing means 170, temperature characteristics of an etalon's transmission peak wavelength and a relation between wavelength and temperature of a laser light source, which have been measured beforehand, are stored. As is the case with the examples of the present invention described above, an error signal 302 based on outputs from two light detecting means 109 and 110 is obtained. As it is found out in this example, allowing for the stored temperature characteristics of the etalon's transmission peak wavelength and the stored relation between wavelength and temperature of the laser light source, a value to be compensated for this error signal is obtained. After that, based on this result, a feedback signal of a fixed value 171 corresponding to a desired emitting wavelength is determined to close a control loop of a wavelength control system. Thus, fluctuations in transmission characteristics based on the etalon's temperature characteristics are compensated, and a signal for controlling an emitting wavelength based on original transmission characteristics of the etalon can be obtained. Members other than those

associated with the artifice in this example are the same
as those shown in Fig. 14. Moreover, a method for
adjusting an emitting wavelength of the laser device
according to an error signal or a feedback signal to fix
the emitting wavelength is the same as that described above.
[0128]

Next, concerning a method for implementing the laser
module according to the present invention, an example is
shown in Fig. 24 and Fig. 25. Fig. 24 is a plan view
illustrating a subassembly in which members of each optical
system and an etalon are equipped on a substrate. Fig. 25
is a plan view illustrating a condition of a 14-pin
butterfly-type transmitter module package 850, on which
desired members of a wavelength-locking optical system
including this subassembly are placed. As shown in Fig. 25,
said subassembly 851 is located facing to face with one
edge of a wavelength-variable laser light source 100, and
an optical-fiber communication line, for example, an
optical fiber 114 as its typical example is located on the
other edge. In this example, a collimator element 102 (for
example, a collimator lens) is located between the laser
light source 100 and the subassembly 851; and a collimator
element 111 (for example, a collimator lens, an optical
isolator 112, a condensing means 113 (for example, a
condenser lens)) are located between the laser light source

100 and the optical fiber 114.

[0129]

In this example, as shown in Fig. 24, an etalon 106, a beam splitter 104, light detectors 109, 110, 115 are placed on the substrate 851. The substrate 851 is placed in a light path of a parallel optical system emitting at a desired wavelength, which has been prepared in another place beforehand, and then an incident angle of light to the etalon is adjusted and fixed to make a subassembly. After that, the subassembly is placed in a light path of a parallel optical system emitting at a desired wavelength, which has been prepared in the package 850. This incident angle to the etalon is equivalent to the incident angle explained in the general description of the etalon. This method provides an advantages of implementation resulting from using parallel plane waves according to the present invention. It is also possible to use the following method: mounting members other than an etalon on a module package; and after that, mounting the etalon on the module package. This example has an advantage of implementation that it is easy to build an optical-fiber communication equipment including an etalon into one package.

[0130]

In other words, integration of the wavelength-locking portion into a subassembly in this manner has an

advantage that it is not necessary to make fine adjustment of a distance between the diode laser and the condenser lens because an angle of divergent light arriving at the etalon as incident light is adjusted. Furthermore, it is also not necessary to make fine adjustment of a tilt angle of the etalon while observing an output from twin light detectors. The present invention provides the extremely great advantage of implementation like this.

[0131]

Fig. 26 shows another embodiment according to the present invention. This is an example showing that a wavelength-variable diode laser device comprising a plurality of luminous portions is used.

[0132]

To be more specific, a plurality of wavelength-variable light sources 951 similar to that shown in Fig. 20 are placed in parallel. Each emitted light is focused on a waveguide 952. On the wavelength-variable light sources 951, a heater 950 to permit a wavelength to be variable is equipped by means of integration. The focused light is gathered by a wavelength multiplexer and demultiplexer 953, and amplified by a semiconductor optical amplifier 954. After that, the light is modulated by an electric absorption modulator 955, and then is emitted from an end of a waveguide substrate. The emitted light is collimated

by the collimator lens 956 as shown in Fig. 11, reflected by the beam splitter 601, and reaches the etalon 106, which constitutes the wavelength-locking optical system described above. Light transmitted through the beam splitter 601 reaches the optical fiber 114 via the isolator 112 and the condenser lens 113. As a result, information is transmitted. In this configuration, as described above, matching FSR of the etalon 106 with the ITU-TS grid, and changing a wavelength of each laser of the laser light sources 951 by turns permit an output wavelength of the fiber 114 to be variable throughout a range wider than that in the case of one laser light source. In addition to it, wavelength fixing also becomes possible. Such wavelength-variable light source is useful as a light source for a high-capacity wavelength division multiplexing optical-fiber communication system as a matter of course. It is also useful as a light source for a wavelength-channel changing switch, that is to say, a light source for a router.

[0133]

Needless to say, as regards an optical system and the like having a configuration like this, which uses a method for locking a wavelength of a laser light source, the various methods described above can be applied to them.

[0134]

Next, a portion of the diode laser device in this example is described in detail. Fig. 27 is a plan view illustrating a wavelength-variable diode laser device similar to said diode optical element portion 106. To be more specific, regarding the wavelength-variable diode laser device in this example, a laser luminous portion 1121 is equipped with a temperature control means 1122. In addition, a light modulator 1125 is also equipped with a temperature control means 1126. Significance of providing the light modulator with the temperature control means is described above. Fig. 28 is its sectional view in a traveling direction of light. In this connection, this sectional view is shown along an optical waveguide. Therefore, it is not a correct sectional view of the device shown in Fig. 27.

[0135]

The diode optical element portion 1121 is formed by an InP/InGaAsP material or an InP/InGaAlAs material, or by both of them. As a substrate 1120 used for forming the diode optical element portion 1121, InP is used. A laser array portion 1121 is located on one side of the diode optical element portion of this example. The laser array portion 121 of this example is a multi-wavelength distributed feedback laser array. In this connection, as a laser device, not only DFB type but also a DBR (Diffraction

Bragg Refraction) type laser device can also be used. Even for the DBR type laser device, supplying a feedback signal according to the present invention to a member having a function of controlling a wavelength can also achieve the object. As shown in Fig. 27, in this example, the multi-wavelength distributed feedback laser array portion 1121 comprises a plurality of laser element portions (1131, 1132, 1133, 1134) having a luminous peak in proximity to a wavelength portion from 1530 to 1562 nm. Fig. 27 is a diagram showing that a modulated signal 1145 from outside is selected by a switch 1144, and that the signal is further passed through signal systems 1140 though 1143 to drive each of diode laser elements 1131 through 1134. As regards a signal system to each of heater portions 1122, an input is similarly provided.

[0136]

Light with each wavelength of the laser array portion 1121 is multiplexed by a light multiplexer 1123. Then, the optical waveguide optically passes the light from the light multiplexer 1123 to the light modulator 1125 via an optical amplifier 1124. The light modulator 1125 in this example is a well-known electric-absorption type semiconductor light modulator. The light is input to the light modulator 1125 after it is optically amplified by the optical amplifier 1124. In addition, an edge of the

element on the light modulator side is covered with a low reflection film 1127; and an edge on the laser side is covered with a high reflection film 1128. The light is emitted from this low reflection film 1127 toward outside of the optical diode device. In this example, temperature control means 1122 and 1126 (by the way, these reference numbers are generic names of the means) are placed in proximity to each laser element portion of the laser array portion 1121 and the light modulator 1125. In Fig. 27, each individual temperature control means 1122 corresponding to each laser portion is shown as 1145, 1146, 1147, and 1148 respectively. On the other hand, the temperature control means 1126 is a heater for controlling operation temperature of the light modulator 1125.

[0137]

Fig. 28 is a sectional view illustrating this example. An optical waveguide 1150, which uses InGaAsP or InGaAlAs as a chemical-compound semiconductor material, is formed on a semiconductor substrate 1120. In this example, a diffraction grating 1151 for a DFB type laser is formed on a surface of the semiconductor substrate InP 1120 beforehand. Forms and production method, which are generally known, may be used for the laser portion 1121, a waveguide portion 1129, the multiplexer portion 1123, the amplifier portion 1124, the light modulator portion 1125,

and others. Optical waveguides 1151, 1152, and 1153 corresponds to the multiplexer portion 1123, the amplifier portion 1124, and the light modulator portion 1125 respectively. An InP layer is formed on each of those optical waveguides to make a clad layer 1160 for performing optical waveguide. In this connection, an InP layer having a window structure 154 is provided on a light emission portion side to reduce light absorption as much as possible. [0138]

On this layer, electrodes 1121 of the diode laser portion and the light modulator portion are formed. In addition to it, after a silicon dioxide film of an insulating layer 1149 is coated with the layer, the heater portions 1122 and 1126 such as Pt or Ti are further formed on the layer. By the way, on the reverse side of the semiconductor substrate, a n-side electrode 1135 is formed. A reference number 1155 is a passivation film on the surface of the device. The diode optical device prepared in this manner is mounted on a heat sink 1150 and a chip carrier 1152 as it is generally mounted. After that, all of them are further mounted on a temperature controller 1102 coated with an adhesive layer 1153. This temperature controller 1102 is a general Peltier cooler. [0139]

Applying a desired current to each of the heater

portions 1122 for controlling a laser emitting wavelength
(each individual heater is shown as 1131 through 1134
respectively) permits a temperature of each laser element
portion to be controlled. As a result, using the functions
of selecting a laser channel to be operated and providing a
variable wavelength in combination enables us to produce a
wavelength ranging from 1530 to 1562 nm, that is to say,
continuous wavelengths. To be more specific, it is
possible to select a desired laser portion of the diode
laser array portion, and at the same time to control an
emitting wavelength for example at said intervals of 4 nm
to cope with a slight wavelength shift of the laser portion.
Accordingly, fine adjustment can be made for the wavelength
settings that are specified in the field of wavelength
division multiplexing optical-fiber communication systems
as described above. When operating this optical element,
the heater 1126 for controlling an operation temperature of
the modulator is energized in response to an input-light
wavelength λp. Thus, light modulation in response to an
emitting wavelength can be performed.

[0140]

Fig. 29 and Fig. 30 are diagrams illustrating the
following: a control system for controlling a driving
current value of the diode laser element portion and a
driving current value of the heater according to an

emitting wavelength of the diode laser element portion; and a control system for controlling a driving current value of the light modulator's heater. Fig. 29 illustrates an example showing that its wavelength detecting portion and the optical diode device of this embodiment are monolithically integrated. Fig. 30 illustrates an example showing that the wavelength detecting portion and the optical diode device of this embodiment are integrated in a hybrid method. As shown in Fig. 29, a means 1050 for detecting a wavelength of the diode laser element portion is provided in combination. A laser-wavelength detecting means 1050 is constructed of an array waveguide diffraction grating 1021. This array waveguide diffraction grating 1021 separates and detects light having each wavelength. The light is then introduced into a signal processing portion 1023 via an optical waveguide 1022. A given signal from this logic circuit 1024 is input to an electrode 1131 of each diode laser element, or to a heater 1145 mounted on the diode laser element, via a control system 1025 for controlling a driving current of the diode laser device or a control system 1026 for controlling a temperature of the diode laser element.

[0141]

In addition, regarding control of the light modulator's heater, a desired signal resulting from

detection of fluctuations in wavelength by the diode laser

element portion is input to the heater 1126 of the light

modulator via a control system 1027 of the light

modulator's heater in a similar manner. By the way, in Fig.

29 and Fig. 30, the same reference numbers are used if the

same members are used in common. A reference number 1125

is an electrode of the light modulator. Fig. 30

illustrates an example showing that an optical diode device

1120 and a laser wavelength detecting means 1050 associated

with this embodiment are integrated in a hybrid manner.

[0142]

As regard a light modulator in the diode laser

device of this example, its temperature is controlled by a

temperature controlling means. Moreover, the light

modulator is also capable of controlling its temperature in

response to a change in emitting wavelength caused by a

change in temperature. Thus, it is possible to change

optical characteristics of the light modulator in response

to a change in temperature of the laser emitting portion to

compensate a shift of the characteristics in response to

the change in temperature. As a result, desired optical

characteristics can be obtained.

[0143]

Next, as an embodiment of an optical system using a

laser module according to the present invention, wavelength

division multiplexing optical-fiber communication equipment

is exemplified. The equipment uses a 1.55 μ m wavelength

band. Fig. 31 is a diagram illustrating a configuration of

an optical-fiber communication system's main portion. This

example shows that an optical transmission light source is

configured by a group of light sources having a fixed

wavelength. An optical-fiber communication system

illustrated in Fig. 31 comprises a wavelength division

multiplexing optical transmission portion 801, an optical

preamplifier 802, an optical fiber 803, an inline amplifier

804, an optical post-amplifier 805, and a light receiving

portion 806. As a light source having a fixed wavelength

807, various kinds of wavelength-variable diode laser

devices according to the present invention described above

can be used. To be more specific, a plurality of DFB diode

laser elements are used as the light source having a fixed

wavelength. An emitting wavelength of each channel is

ranging from 1532.29 to 1597.19 nm at intervals of 50 GHz;

160 channels in total. Signal light from each channel of

the light source is multiplexed into one fiber 810 by a

wavelength multiplexer 809 that uses a diffraction grating

using a general array waveguide. A means for locally

controlling temperature of the diode laser element portion

according to the present invention enables adjustment to

the emitting wavelength described above.

[0144]

This example enables us to miniaturize the device and to improve economical efficiency as compared with the conventional configuration. Using this simple configuration, a light-wave signal wavelength of each channel can be set to a desired value, and can be stabilized, by means of an easy artifice. Therefore, it is possible to realize a wavelength division multiplexing communication system with high reliability, and at the same time to produce the effect of increasing a number of channel wavelengths as compared with the conventional system, at a low cost.

[0145]

As described in detail, using configurations comprising basic elements according to the present invention enables us to exploit the full performance of the etalon. That is to say, according to the present invention, the technical problems are solved, which could not be conventionally overcome from the viewpoints of: resolution of wavelength selection; optical efficiency; increase in density of implementation into a laser light source module; mechanical stability; compensation for a locking-wavelength shift caused by a change in temperature; and the like. Furthermore, if the wavelength control method according to the present invention is utilized, it becomes possible not

only to lock a diode-laser's emitting wavelength but also to transfer and lock the wavelength to an arbitrary ITU-TS grid. This method, therefore, provides us with a laser light source that is indispensable for the wavelength division multiplexing optical-fiber communication equipment and a router device for wavelength channels.

[0146]

[Effects of the Invention]

The present invention can provide a diode laser light source that is capable of locking an emitting wavelength of the diode laser light source to a specified value with high accuracy. This optical system can be separately operated as a wavelength locker module. However, the optical system can also be built into an optical-fiber transmitter module comprising a laser light source because of its smaller size.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a configuration diagram illustrating a conventionally known wavelength-control light source.

[Fig. 2]

Fig. 2 is a diagram illustrating an example of a wavelength monitoring control device for a wavelength division multiplexing optical-fiber communication system that uses an etalon.

[Fig. 3A]

Fig. 3A is a sectional view illustrating a condition of light by an etalon.

[Fig. 3B]

Fig. 3B is a diagram illustrating an example of a relation between phase difference and transparent light regarding an etalon.

[Fig. 4]

Fig. 4 is a diagram illustrating an example of a relation between temperature and emitting wavelength in a diode laser device.

[Fig. 5]

Fig. 5 is a configuration diagram illustrating an example of a wavelength-control light source according to the present invention.

[Fig. 6]

Fig. 6 is a diagram illustrating an example of a relation between wavelength difference and an error signal in an exemplified module of the present invention.

[Fig. 7]

Fig. 7 is a diagram illustrating an example of a condition of an external resonator in a diode laser device.

[Fig. 8A]

Fig. 8A is a diagram illustrating an example of relations among a diode laser device, a collimator lens,

and a light detector.

[Fig. 8B]

Fig. 8B is a diagram illustrating another example of relations among a diode laser device, a collimator lens, and a light detector.

[Fig. 9]

Fig. 9 is a diagram illustrating an example of placement of a wavelength-locking optical system according to the present invention.

[Fig. 10]

Fig. 10 is a configuration diagram illustrating another example of a wavelength-control light source according to the present invention.

[Fig. 11]

Fig. 11 is a configuration diagram illustrating another example of a wavelength-control light source according to the present invention.

[Fig. 12]

Fig. 12 is a diagram illustrating an example of a relation between phase difference and reflection light regarding an etalon.

[Fig. 13]

Fig. 13 is a diagram illustrating an example of relations among phase difference, reflection light, and transmission light regarding an etalon.

[Fig. 14]

Fig. 14 is a configuration diagram illustrating another example of a wavelength-control light source according to the present invention.

[Fig. 15]

Fig. 15 is a diagram illustrating another example of placement of a wavelength-locking optical system according to the present invention.

[Fig. 16]

Fig. 16 is a diagram illustrating another example of placement of a wavelength-locking optical system according to the present invention.

[Fig. 17]

Fig. 17 is a diagram illustrating another example of placement of a wavelength-locking optical system according to the present invention.

[Fig. 18]

Fig. 18 is a diagram illustrating an example of a relation between phase difference and transmission light regarding an etalon.

[Fig. 19]

Fig. 19 is a diagram illustrating another example of placement of a wavelength-locking optical system according to the present invention.

[Fig. 20]

Fig. 20 is a plan view illustrating an example of a wavelength-variable diode laser device.

[Fig. 21]

Fig. 21 is a sectional view illustrating an example of an etalon of which temperature coefficient is zero.

[Fig. 22]

Fig. 22 is a diagram illustrating a relation between a wavelength-variable method according to the present invention and ITU-TS grid.

[Fig. 23]

Fig. 23 is a diagram illustrating another example of placement of a wavelength-locking optical system according to the present invention.

[Fig. 24]

Fig. 24 is a plan view illustrating an example of a wavelength control module's subassembly according to the present invention.

[Fig. 25]

Fig. 25 is a plan view illustrating an implementation example of a wavelength control module according to the present invention.

[Fig. 26]

Fig. 26 is a plan view illustrating a configuration example of a wavelength control module according to the present invention.

[Fig. 27]

Fig. 27 is a plan view illustrating an example of a wavelength-control diode laser device associated with the present invention.

[Fig. 28]

Fig. 28 is a sectional view illustrating an example of a wavelength-control diode laser device associated with the present invention.

[Fig. 29]

Fig. 29 is a plan view illustrating an example of a control system of a wavelength-control diode laser device associated with the present invention.

[Fig. 30]

Fig. 30 is a plan view illustrating another example of a control system of a wavelength-control diode laser device associated with the present invention.

[Fig. 31]

Fig. 31 is a basic configuration diagram illustrating an example of an optical system.

[Description of Reference Numbers]

101: wavelength-variable laser light source

102: collimator

103: parallel light

104: beam splitter

105: transmitted light

106: Fabry Perot etalon

107: transmitted light

108: reflected light

109: light detector

110: light detector

111: collimator

112: optical isolator

113: condenser lens

114: optical fiber

301: FSR

302: error signal

303: capture portion

401: Peltier cooler

402: Peltier-cooler driving circuit

403: thermistor

404: laser-light-source driving circuit

601: beam splitter

701: etalon having taper

702, 703: light detector

801: shift in transmission peak

802, 803: a change in received-light quantity or photocurrent by a shift in wavelength of light detectors 702 and 703

901, 902: etalon having a different refractive index or a different mechanical length

150: diode laser

151: thin film heater

152: diode laser's electrode

153: electric absorption modulator

154: modulator's electrode

161, 162: glass material

163: silicon gel

170: semiconductor memory

171: specified value

850: 14-pin package

851: substrate

852: subassembly

950: thin film heater

951: diode laser

952: waveguide

953: wavelength multiplexer and demultiplexer

954: semiconductor optical amplifier

955: electric absorption modulator

956: collimator lens

FIG. 1

FIG. 2

FIG. 3A

FIG. 3B

ETALON TRANSPARENT LIGHT

PHASE DIFFERENCE
$= 2\pi (nt/\lambda)\cos(\theta/n)$

FIG. 4

0.1nm/°C

WAVELENGTH OR
ITU-T GRID

$\lambda+2\Delta\lambda$
$\lambda+\Delta\lambda$
λ
$\lambda-\Delta\lambda$
$\lambda-2\Delta\lambda$

$T-2\Delta T$ $T-\Delta T$ T $T+\Delta T$ $T+2\Delta T$

TEMPERATURE OF
DIODE LASER
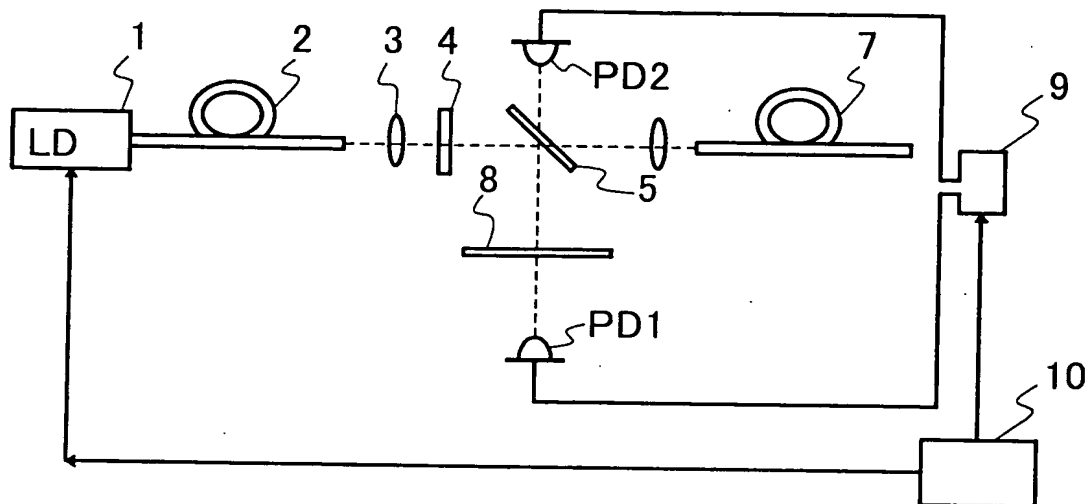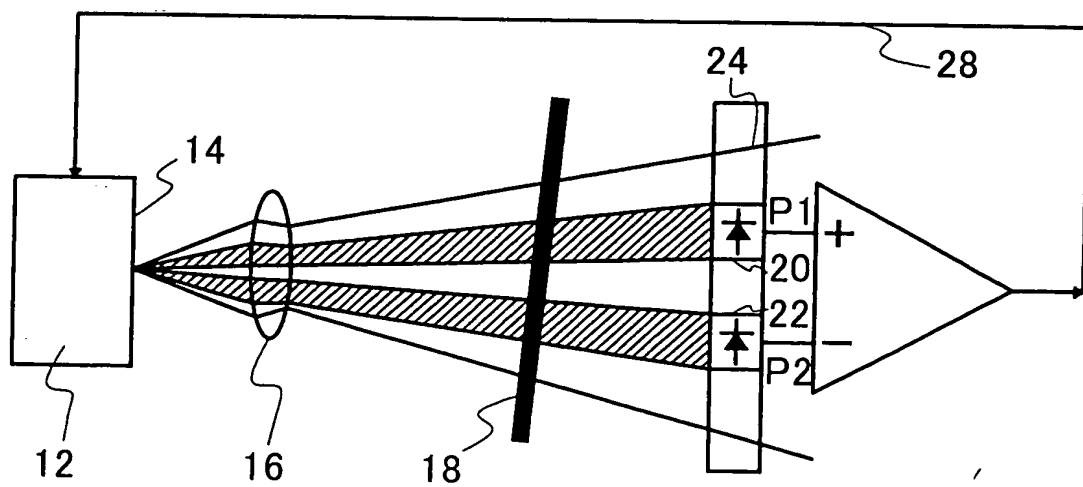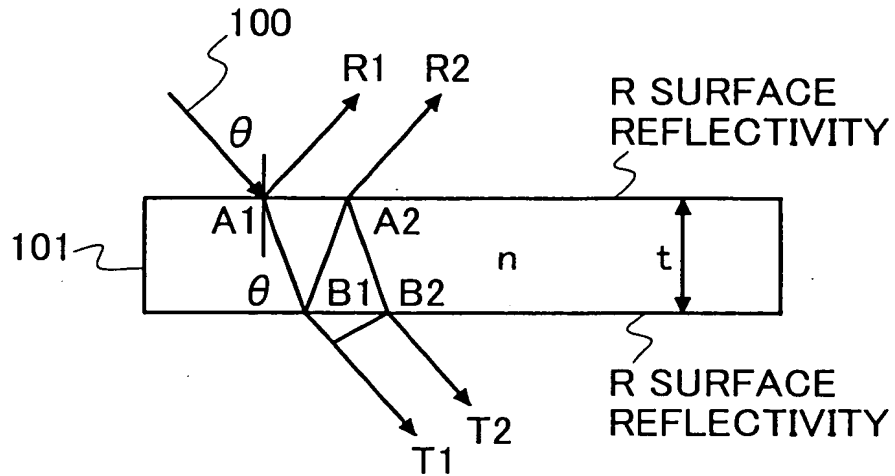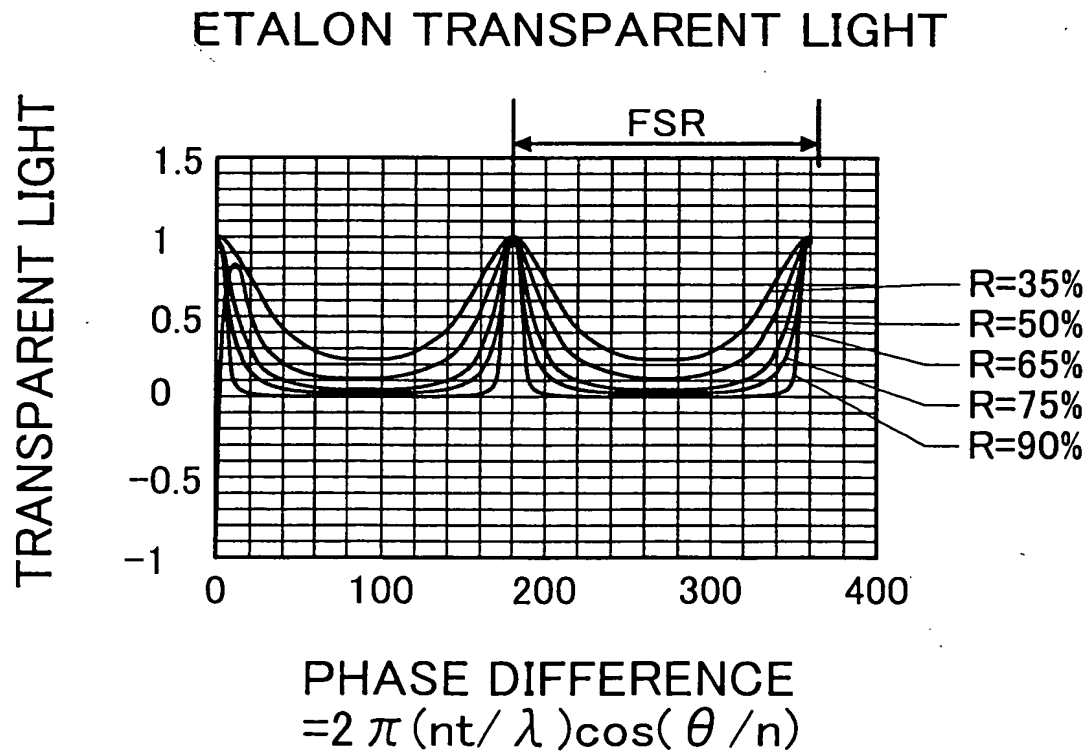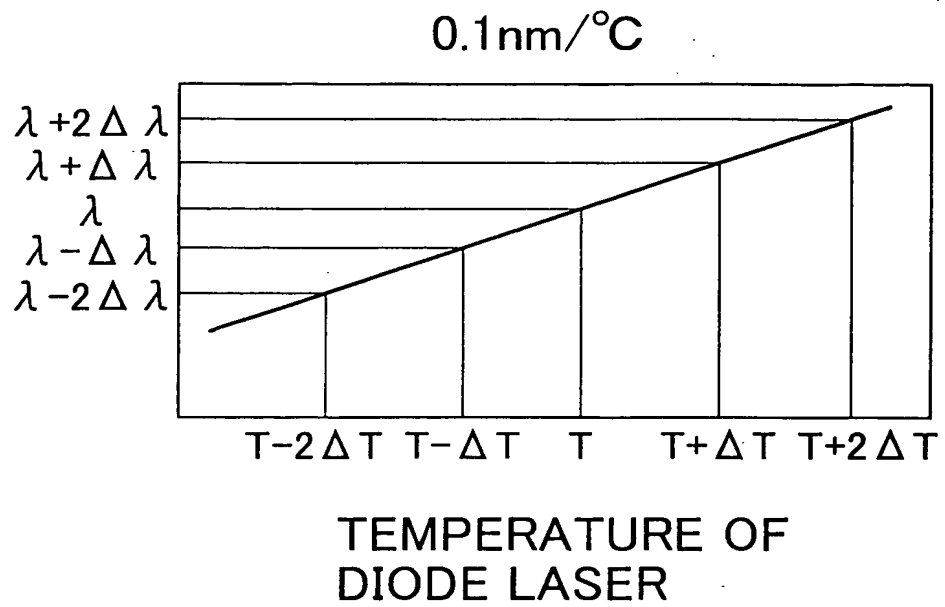
FIG. 5
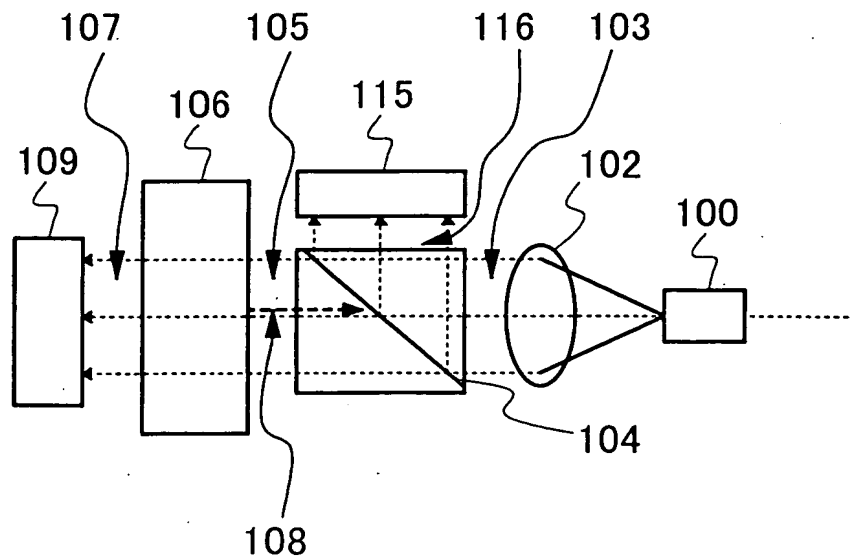
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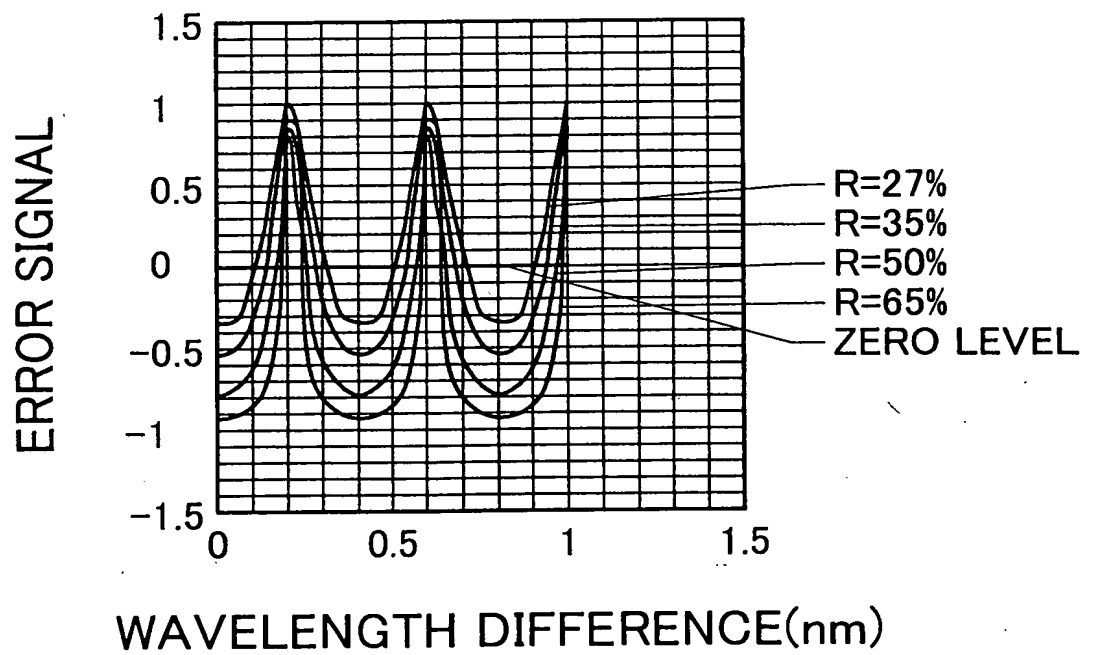
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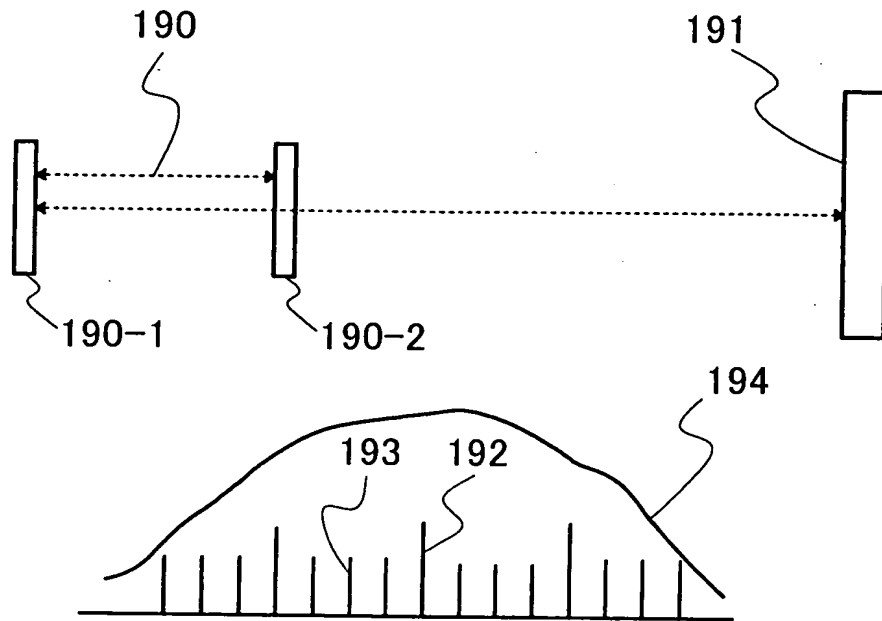
FIG. 8A

FIG. 8B

FIG. 9

FIG. 10

FIXED VALUE — 115

404

100

403

401

402

302

L

104   106   109

FIG. 11

107   105   116   103

109   106   115   102   100   111   112   113   114

104

108   110

FIG. 12

FIG. 13

FIG. 14

FIXED
VALUE — 115

404

101

403

401

402

104

106

L

110

106

109

FIXED
VALUE

302

FIG. 15

109

106

115

102 101

111

104

110

FIG. 16

109

111

106

601

115

101

110

FIG. 17

701

L2

L1 101

115

702

703

601

FIG. 18

LOCKED WAVELENGTH

- ◆ CIRCUIT 1
- ■ CIRCUIT 2
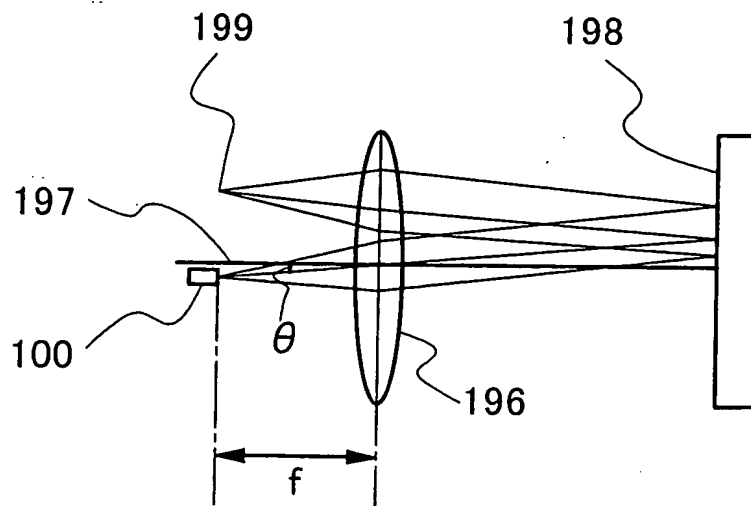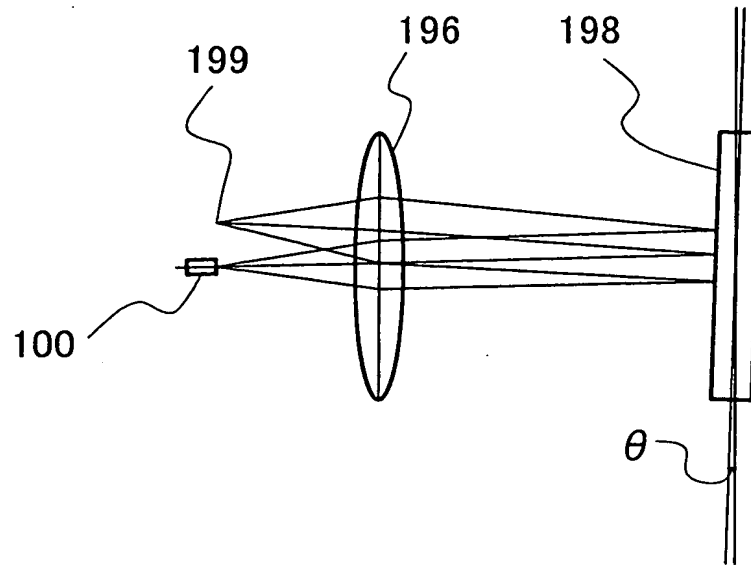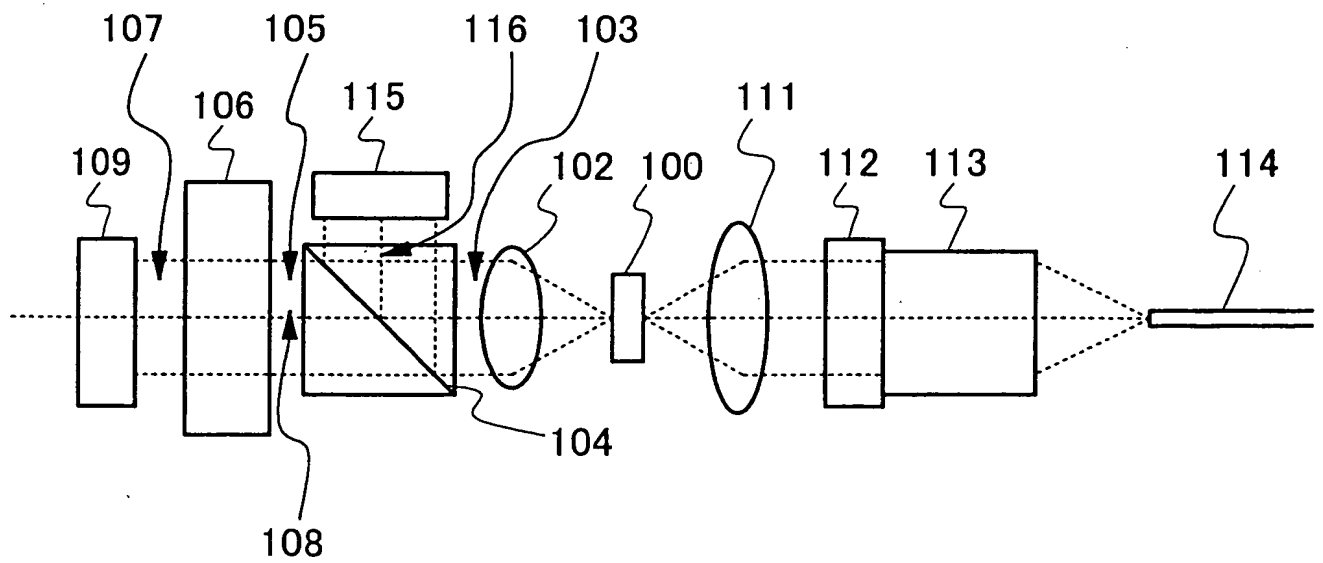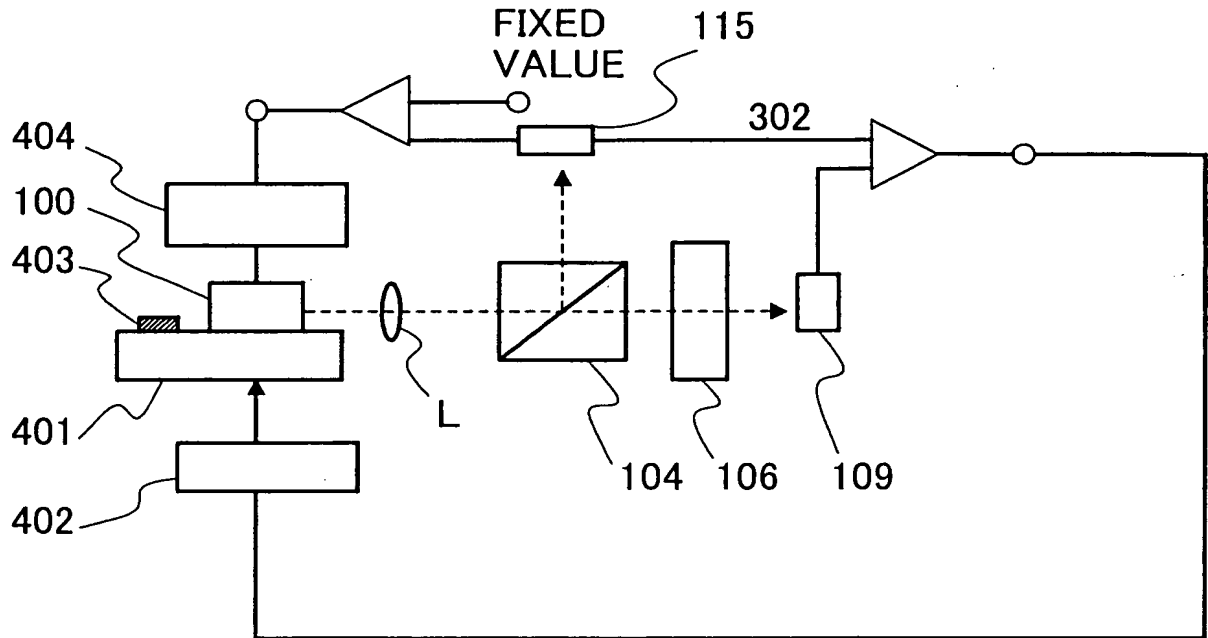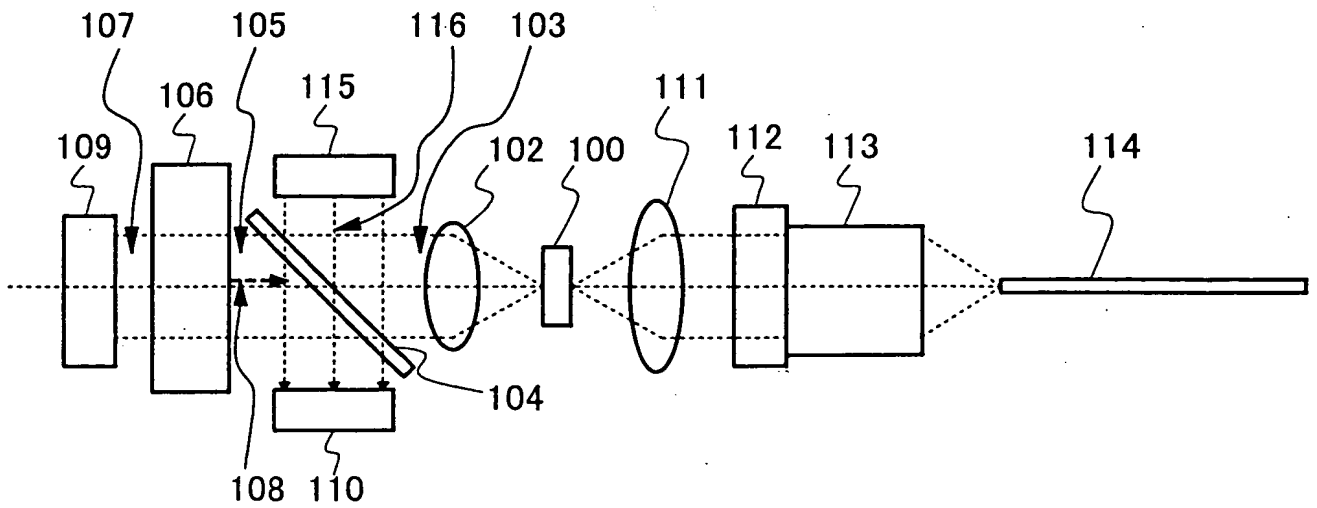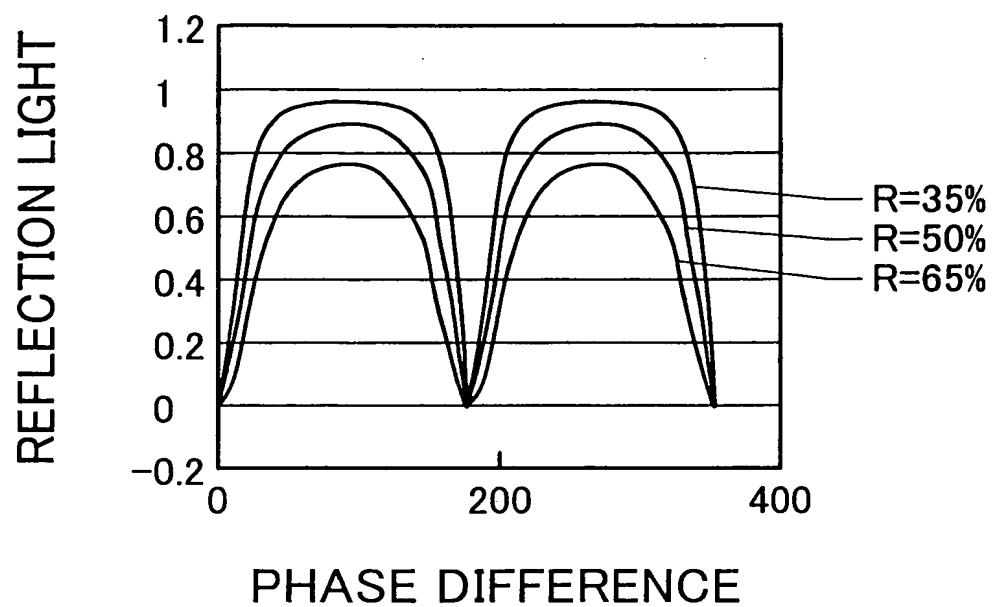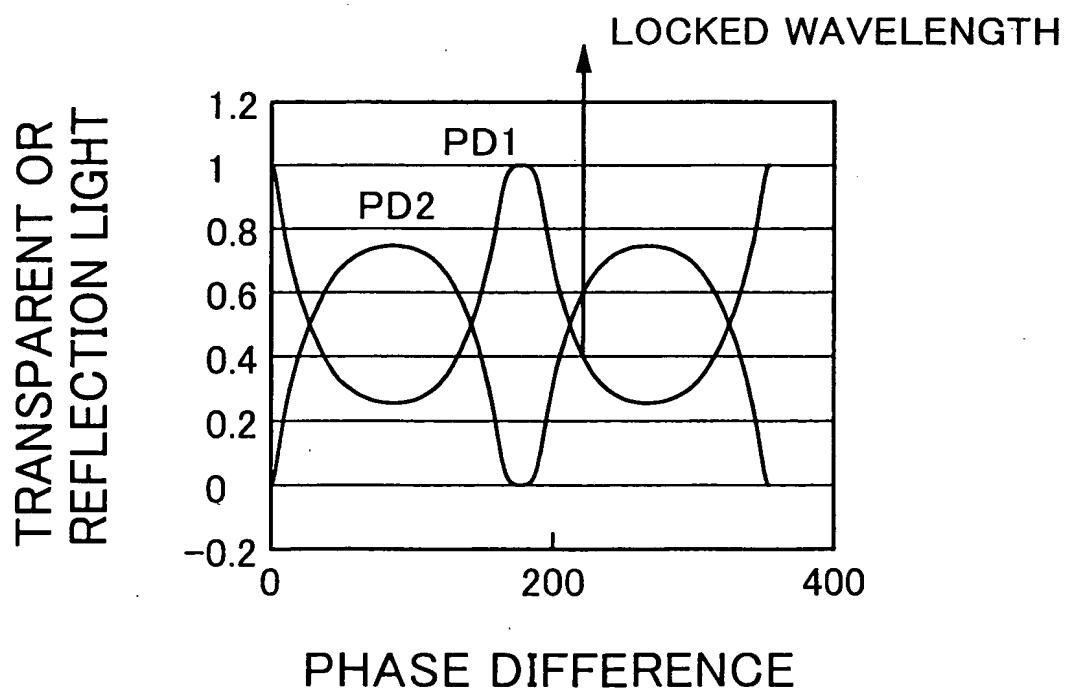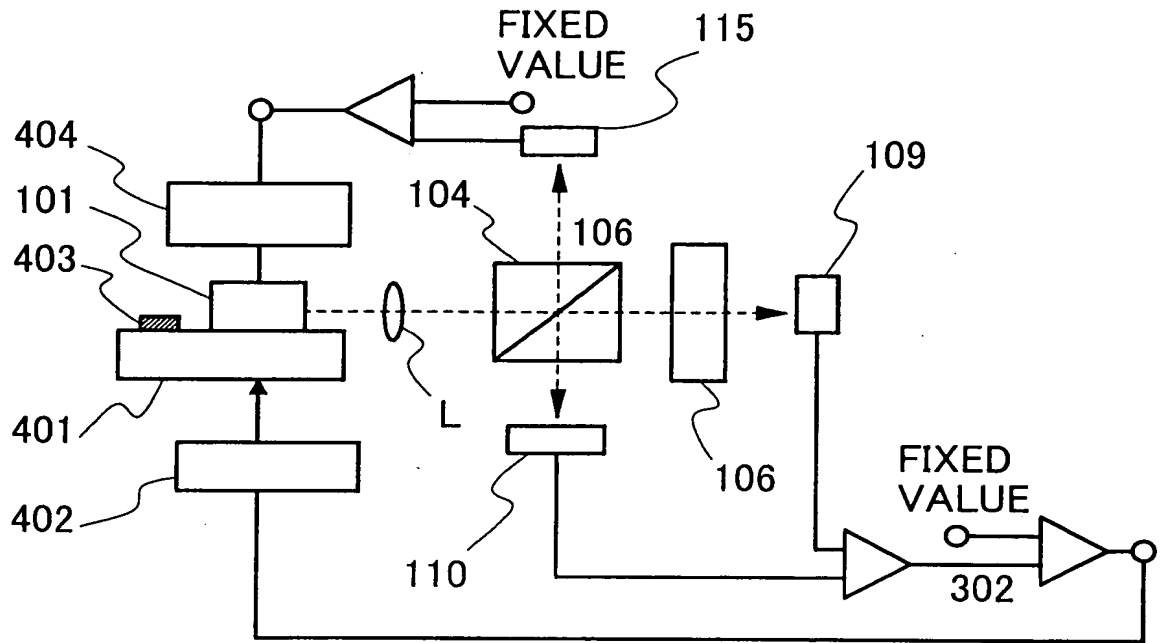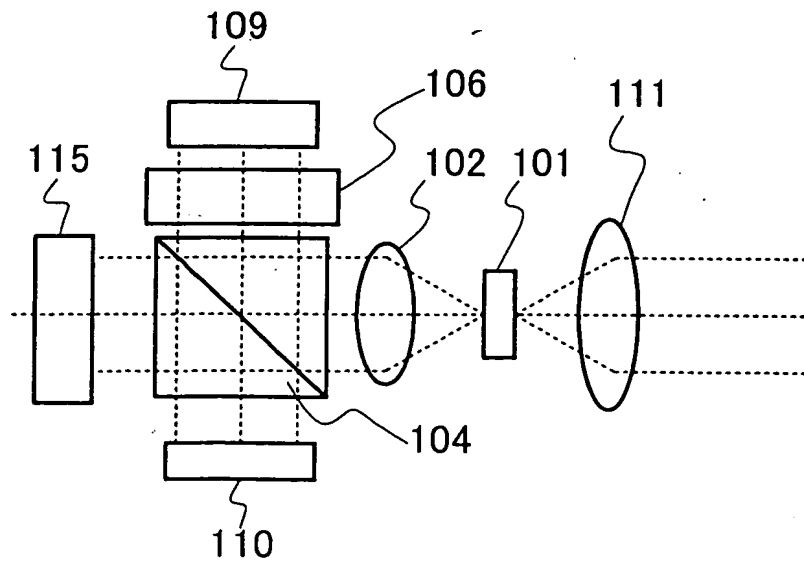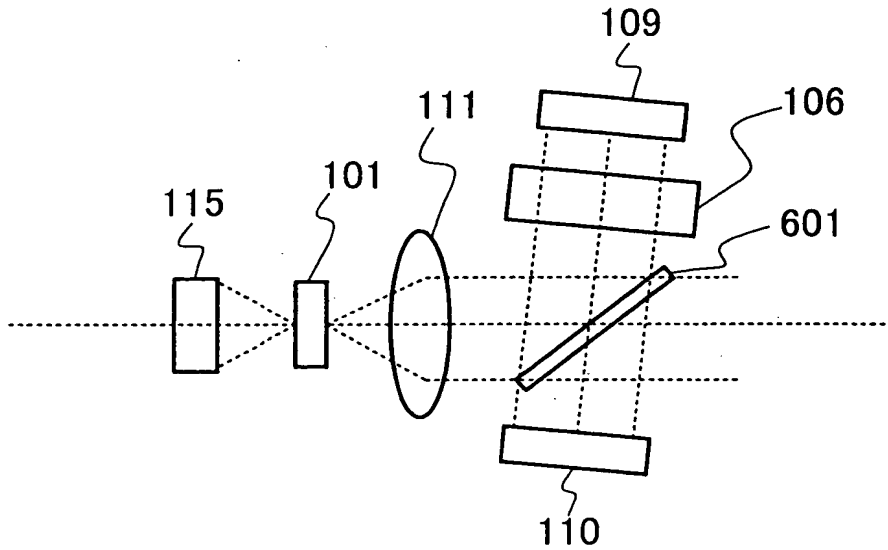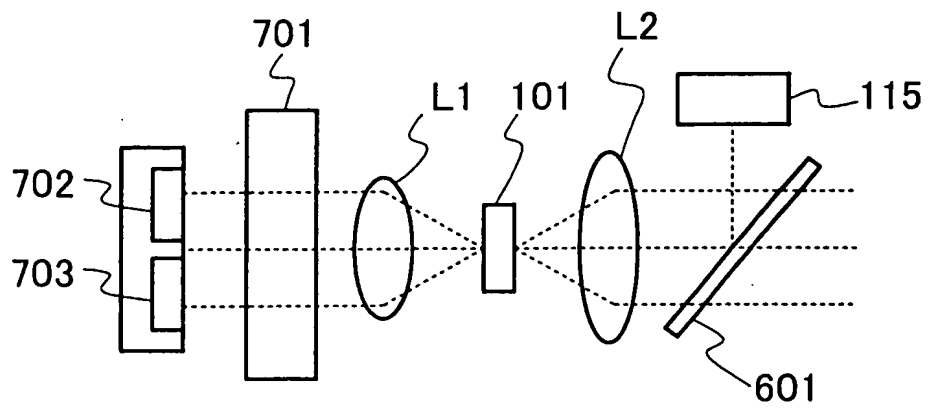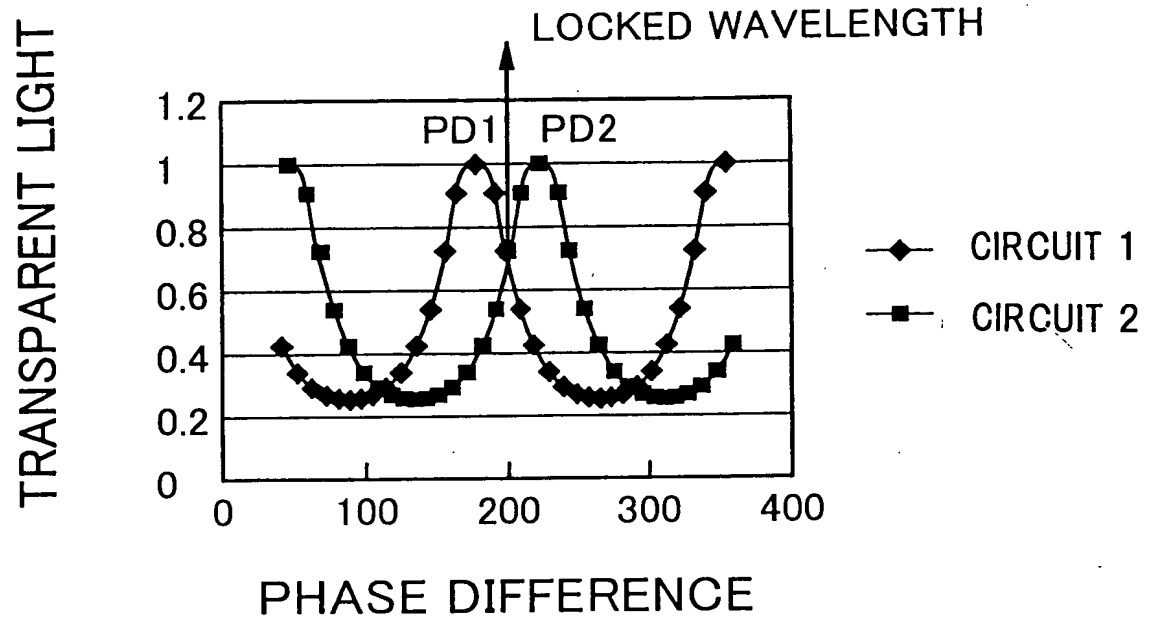
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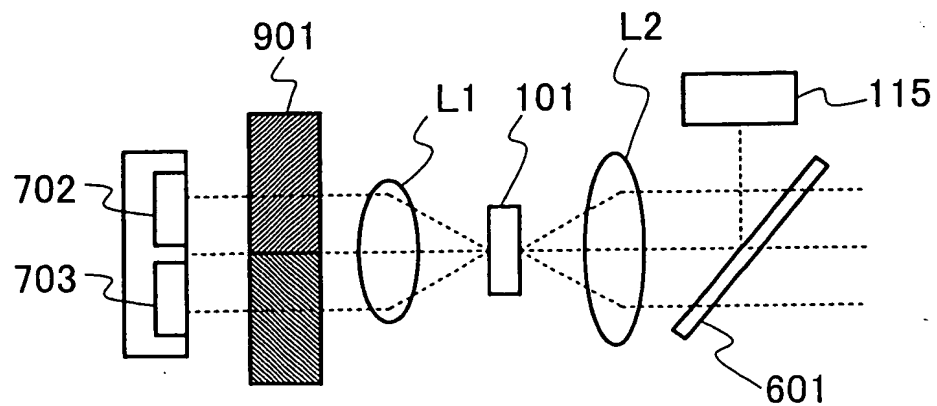
FIG. 20

FIG. 21

FIG. 22

FIG. 23

FIXED
VALUE   115

404

100

403

401

402

104

106

110

106

109

170

171

FIXED VALUE

302

FIG. 24

109   106   115

851   104   110

FIG. 25

850

109 106 115 102 100 112

114

852 110 111 113
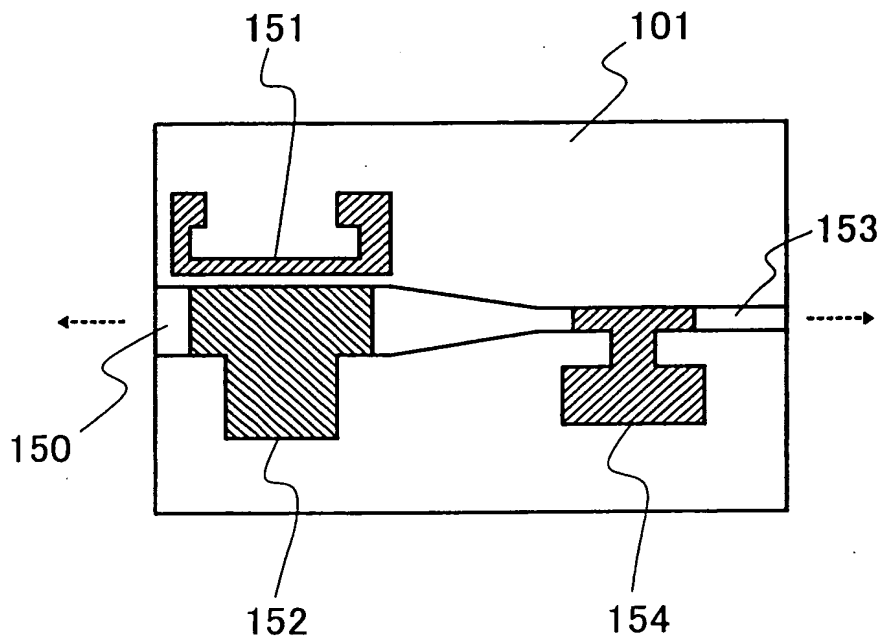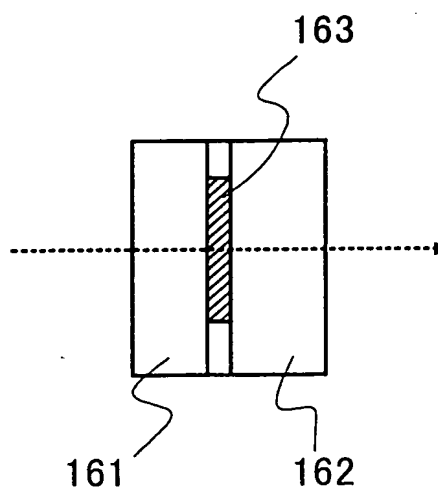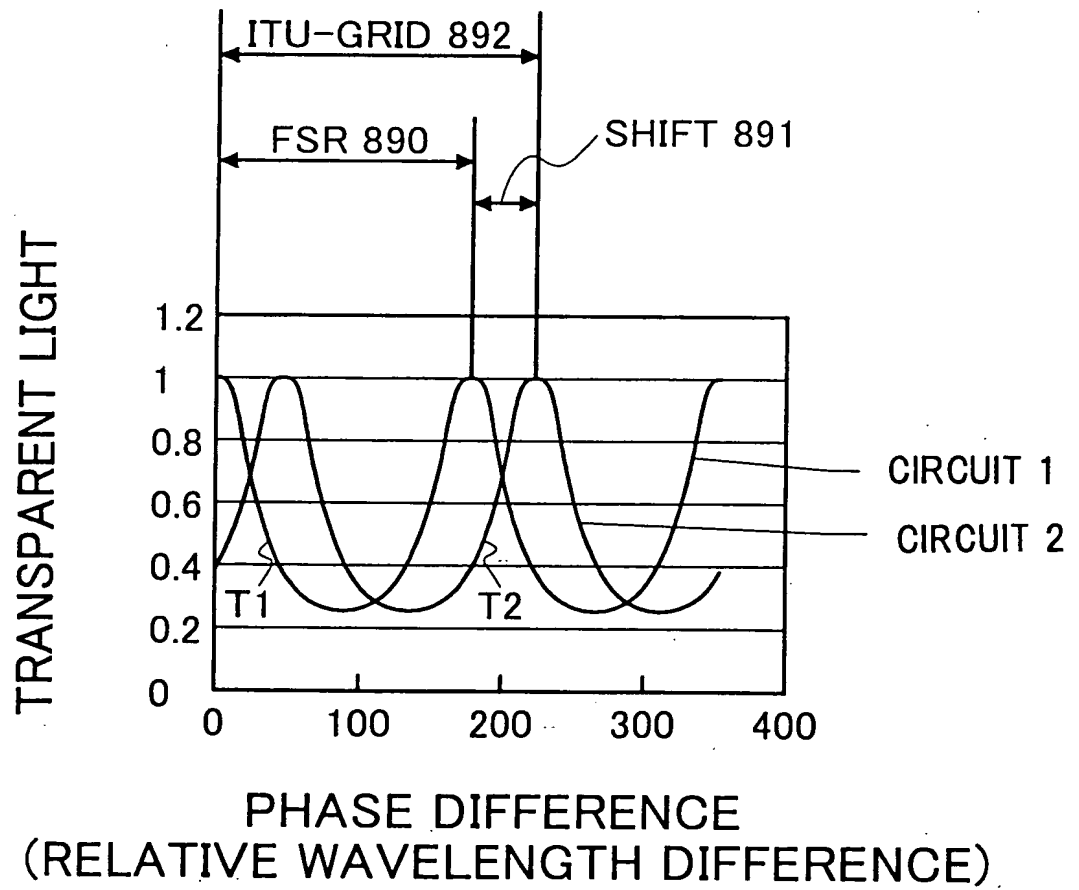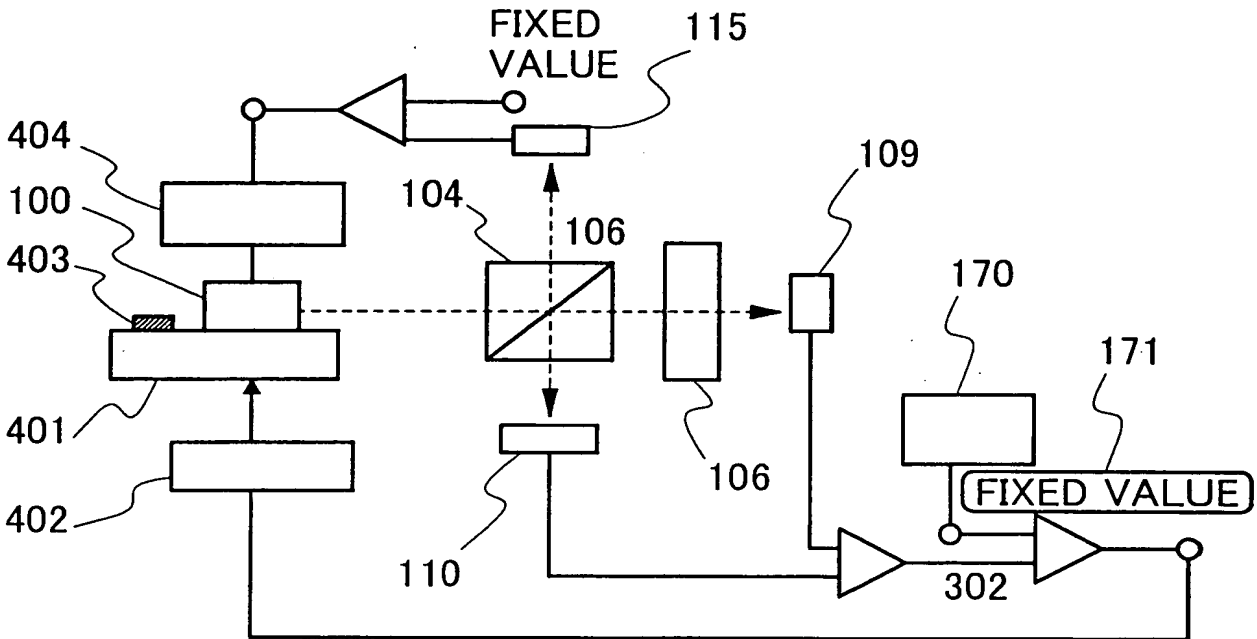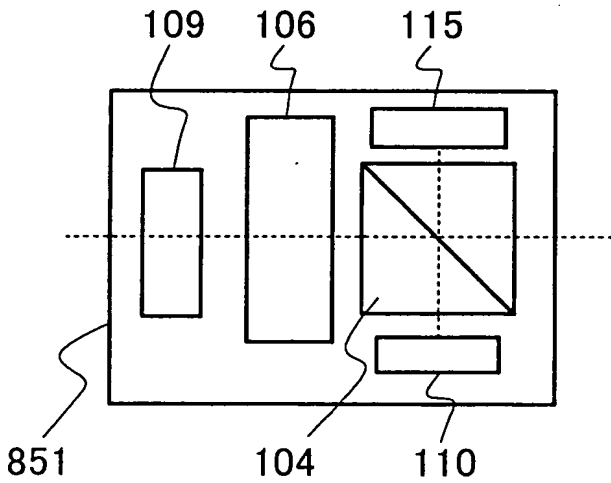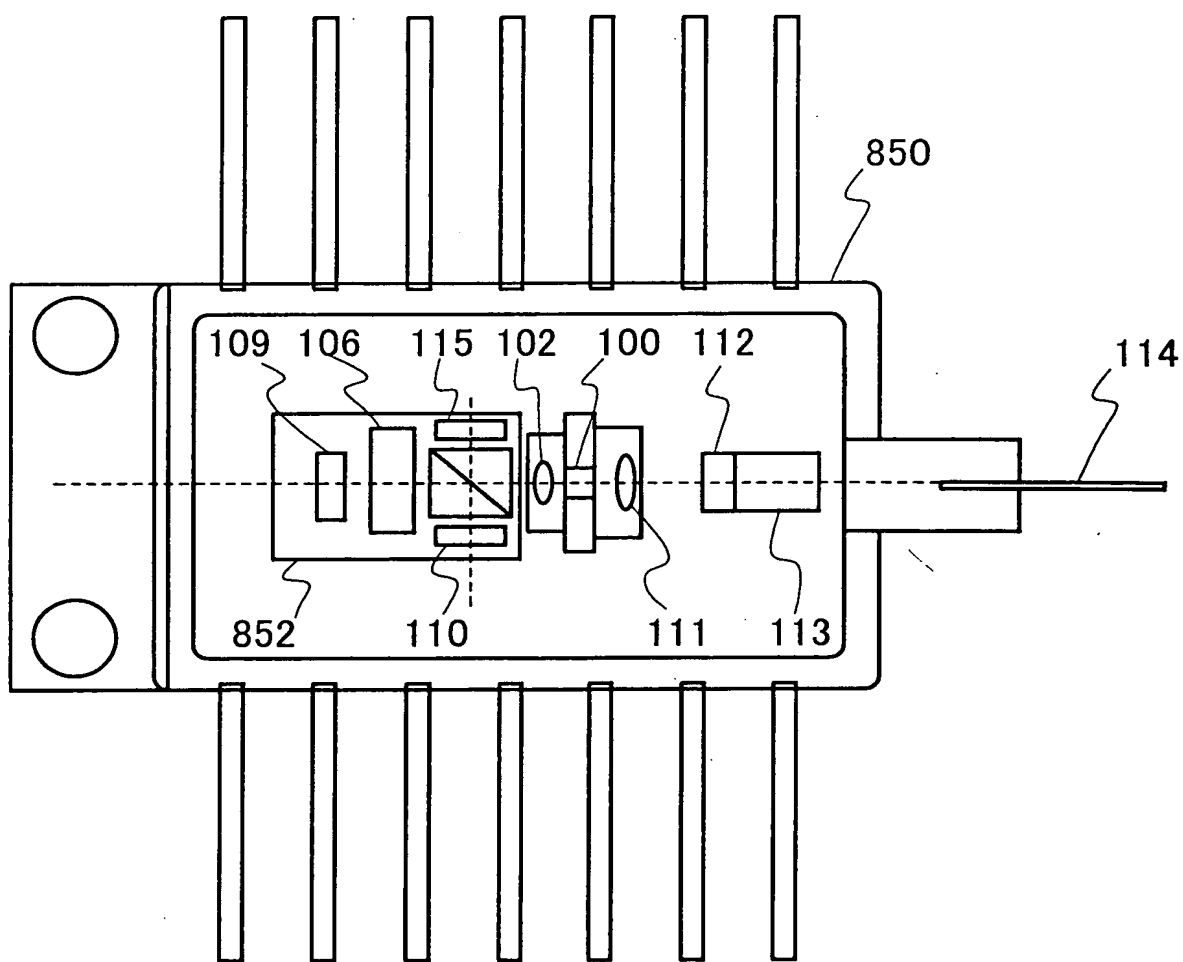
FIG. 26

FIG. 27

FIG. 28

FIG. 29

FIG. 30

1027
1026 1025
1022 1040
1125 1145
1126
1131 1120 1021 1050 1030
1024
1023

FIG. 31

801 802 803 804 803 805 806
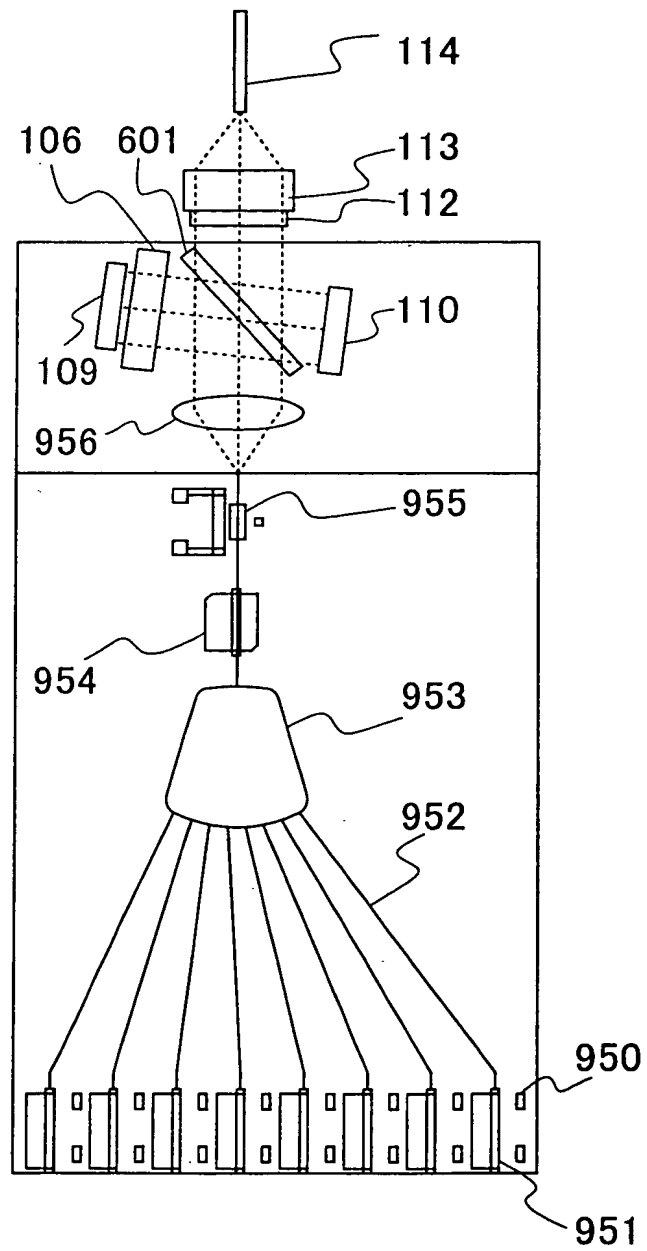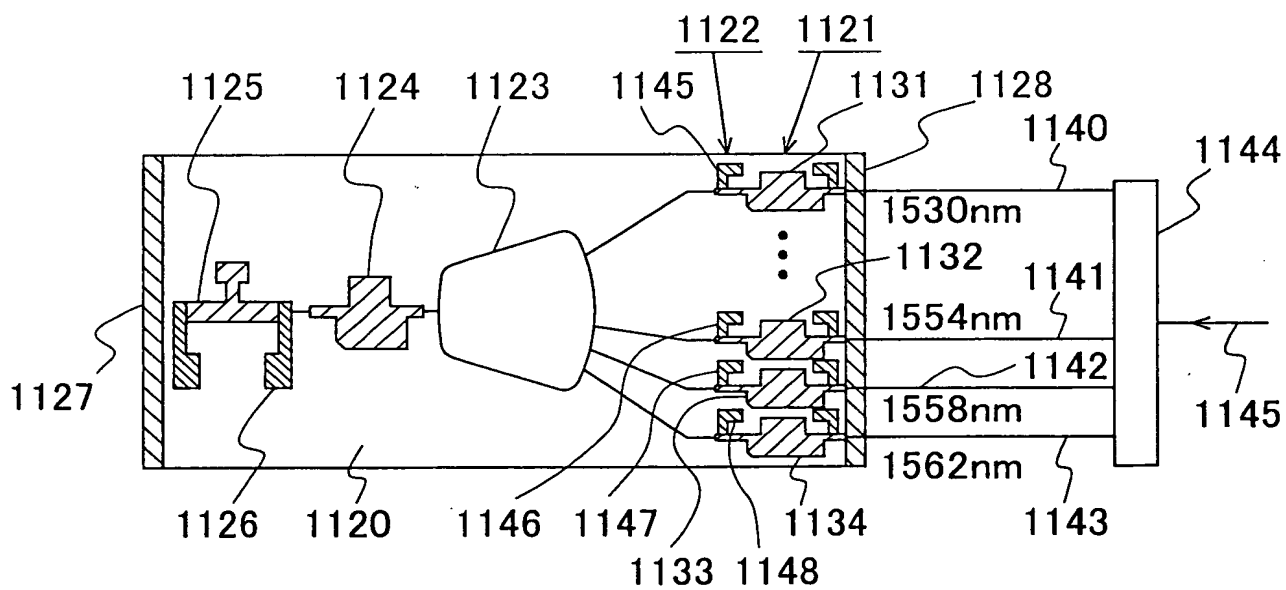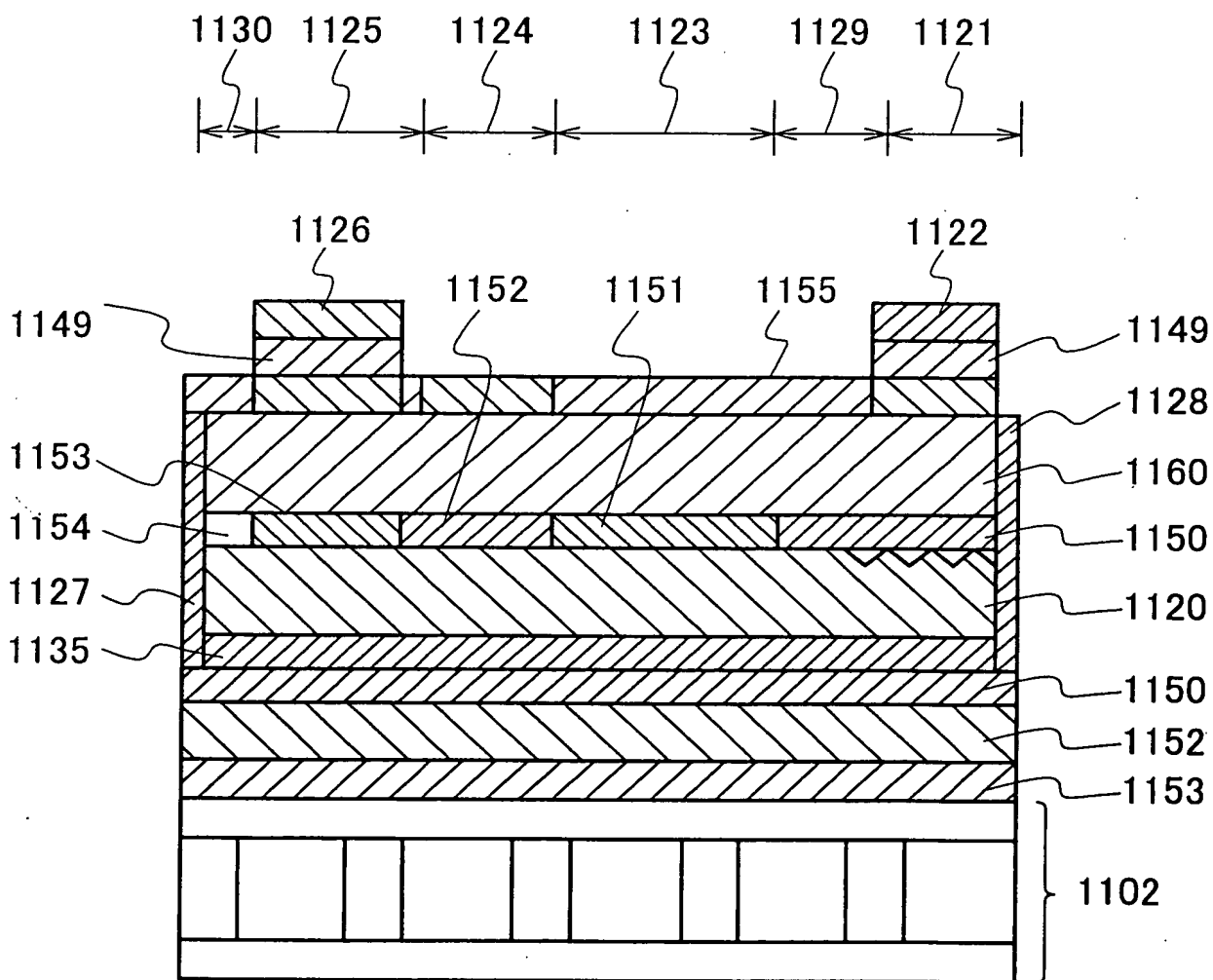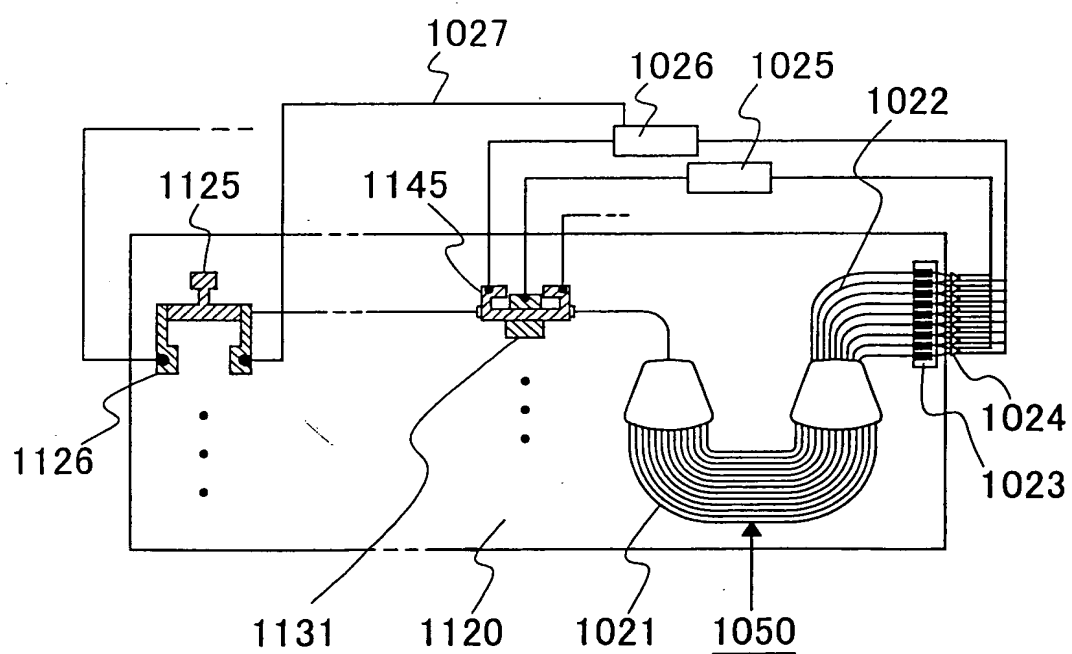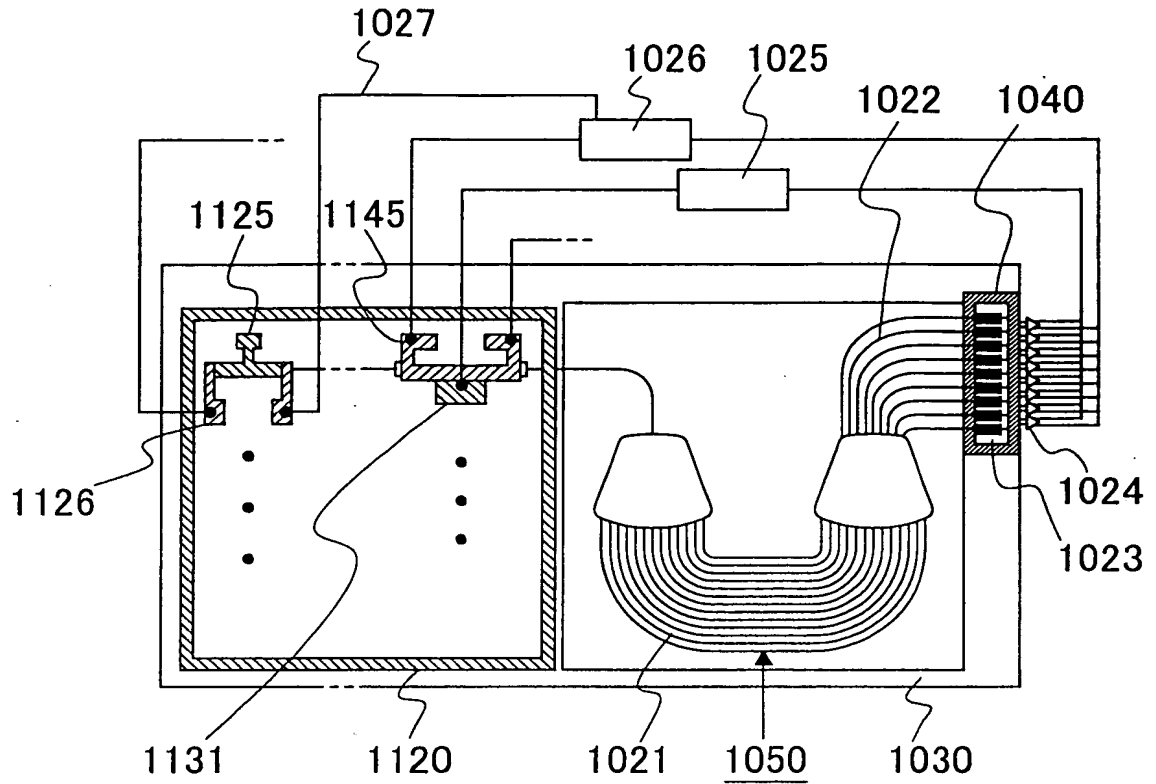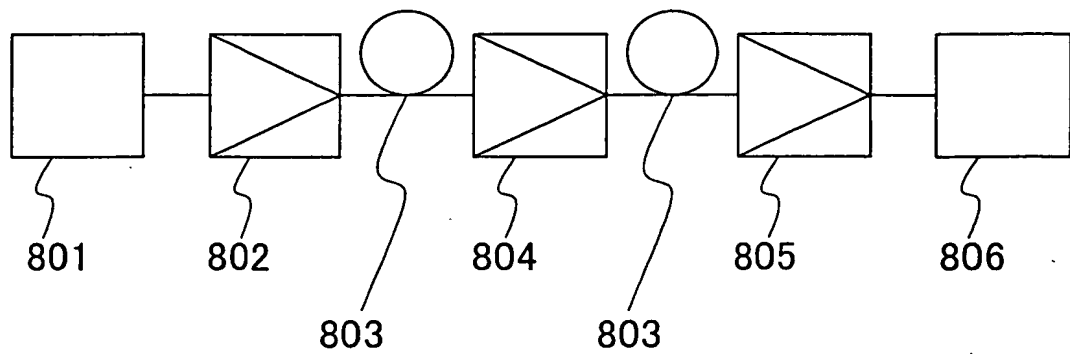
[Name of Document] ABSTRACT

[Summary]

[Object]

An object of disclosed technology is to control emitting wavelengths so that a wavelength shift does not occur. Another object is to permit wavelengths of a light source for wavelength division multiplexing optical-fiber communication system to be variable in response to an ITU-TS grid.

[Solving Means]

A means for achieving the objects is as follows: locating an etalon in a light path of diode laser light, which is a parallel plane wave changed by a collimator liens; generating a wavelength error signal from a difference between both of divided pieces of light from transmitted light or reflected light; and locking a wavelength of a diode laser device according to the wavelength error signal.

[Selected Figure] Fig. 5